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Double-Shell Tank Hydroxide Depletion Model for Carbon Dioxide Absorption

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Abstract: This document generates a supernatant hydroxide ion depletion model based on mechanistic principles. The carbon dioxide absorption mechanistic model is developed in this report. The report also benchmarks the model against historical tank supernatant hydroxide data and vapor space carbon dioxide data. A comparison of the newly generated mechanistic model with previously applied empirical hydroxide depletion equations is also performed.

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DOUBLE-SHELL TANK HYDROXIDE DEPLETION MODEL FOR CARBON DIOXIDE ABSORPTION

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LIST OF TERM**Abbreviations and Acronyms**

AC	administrative control
AWF	Aging Waste Facility
CO ₂	carbon dioxide
ECN	Engineering Change Notice
DST	double-shell tank
GRE	Gas Release Event
NO ₂ ⁻	nitrite
OH ⁻	hydroxide
SHMS	Standard Hydrogen Monitoring System
SRS	Savannah River Site, Aiken, SC
TSR	technical safety requirement
TWINS	Tank Waste Information Network System
WTP	Hanford Tank Waste Treatment and Immobilization Plant

Units

cfm	cubic feet per minute
Btu/hr	British thermal units per hour
cfm	cubic feet per minute
ft	feet
hr	hour
in.	inch
kgal	kilo gallons, 1000 gallons
<u>M</u>	molar concentration (moles per liter)
<u>M</u> /min	molar per liter per minute
<u>M</u> /yr	moles per liter per year
min	minute
mL	milliliters
moles/yr	moles per year
ppm	parts per million
yr	year
µg/mL	micro grams per milliliter
%	percent
°F	degrees Fahrenheit

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1.0 INTRODUCTION

Administrative Control (AC) 5.16, "Corrosion Mitigation Program," is a part of the technical safety requirement (TSR) for the double-shell tanks (DSTs) and Aging Waste Facility (AWF) tanks, HNF-SD-WM-TSR-006, *Tank Farms Technical Safety Requirements*. Administrative Control 5.16 requires a program be maintained to manage the DST waste chemistry to limit corrosion of the primary tank wall. The technical basis for the chemistry control program is documented in RPP-7795, *Technical Basis for Chemistry Control Program*.

Maintaining a minimum specified free hydroxide (OH^-) ion concentration in DST waste is central to the chemistry control program for AC 5.16. The free OH^- ion is consumed or depleted through chemical reactions. Chemical reactions include the depletion of free OH^- ion through the absorption of carbon dioxide (CO_2) from the tank ventilation air. The current technical basis identifies the Hobbs equation for use as a free hydroxide depletion model for CO_2 absorption, RPP-7795. The Hobbs model is an empirical correlation of measured CO_2 absorption rate data (based on solution pH) for eight H-Area tanks from the Savannah River Site, Aiken, SC (SRS), DPST-87-596, *Absorption of Carbon Dioxide in Waste Tanks* (U). The Hobbs correlation is not a mechanistic based model.

An expert panel was convened in April and July 2004 to review three proposed initiatives to optimize the chemistry control program. The three initiatives and expert panel recommendations are contained in RPP-RPT-22126, *Expert Panel Workshop for Hanford Site Waste Chemistry Optimization*. The second initiative included a proposal to minimize core sampling frequency. The Expert Panel for Hanford Site Double-Shell Tank Waste Chemistry Optimization recommended, "the current, schedule-based ... sampling program be suspended as quickly as possible and be replaced with a sampling frequency determined by measurements of the concentration of hydroxide ion in the supernatant layer and the concentrations of hydroxide ion in the sludge estimated by the recently developed Dynamic Mixing Model." The mechanistic based free hydroxide depletion model for CO_2 absorption described in this report, when verified against sample data, will provide an integral engineering tool needed for implementing the expert panel recommendation.

This document presents a mechanistic based free hydroxide depletion model for CO_2 absorption and the benchmark of this model using both Hanford Site and SRS data. A description of the mechanistic depletion model is provided in Section 2.0, along with a description of the Hobbs correlation. The Hanford Site and SRS benchmark data are contained in Section 3.0, including Hanford Site OH^- ion concentration sample data and the OH^- ion depletion rate obtained from these data. Section 4.0 presents the results of the mechanistic hydroxide depletion model benchmark using Hanford Site and SRS data. The benchmark of the mechanistic hydroxide depletion model with the Hanford Site data includes a comparison of the predicted and measured OH^- ion depletion rates and vapor space CO_2 concentrations. The benchmark of the mechanistic hydroxide depletion model with the SRS data includes a comparison of the predicted and measured CO_2 absorption fraction (fraction of CO_2 in ventilation air absorbed by OH^- ions in the tank supernatant).

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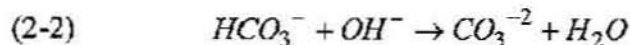
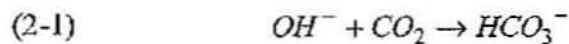
This report is prepared by John Marvin, Inc., for CH2M HILL Hanford Group, Inc. It has been independently reviewed by John Marvin, Inc., staff per the Quality Assurance requirements of John Marvin, Inc. The John Marvin, Inc., reviewer's checklist is provided in Appendix A.

2.0 HYDROXIDE DEPLETION MODEL

The free OH^- ion concentration of the waste stored in Hanford Site DSTs is maintained within established limits or adjusted if the chemistry control limits are challenged or exceeded. Hydroxide, along with nitrite ions, in the waste protects the primary carbon steel tank walls from general corrosion, pitting corrosion and stress-corrosion cracking. The free OH^- ion is depleted through absorption of CO_2 from the tank vapor space, oxidation of sodium salts of organic species, and reaction with hydrated aluminum oxide, RPP-7795. A description of the OH^- ion depletion mechanism from CO_2 absorption and the Hobbs and mechanistic hydroxide depletion models is provided in the following sections.

2.1 HYDROXIDE DEPLETION MECHANISM

Free OH^- ions in the supernatant are consumed through the absorption of CO_2 from the primary ventilation system air stream. The reactions are shown in Equations 2-1 and 2-2.



Two moles of OH^- ion are consumed or depleted for each mole of CO_2 absorbed.

2.2 HOBBS MODEL

The Hobbs model is currently used to predict the rate of OH^- depletion through CO_2 absorption for some Hanford Site DSTs, RPP-7795. The Hobbs model is based on an empirical correlation of SRS data. The OH^- ion depletion rate for the Hobbs model is given by Equation 2-3.

$$(2-3) \quad \text{OH}_{\text{dep}} = 2 \cdot Q_{\text{vent}} \cdot [\text{CO}_2]_{\text{air amb}} \cdot F$$

Where:

OH_{dep} is the OH^- ion depletion rate (moles per unit time).

Q_{vent} is the primary ventilation volumetric flow rate (volume per unit time).

$[\text{CO}_2]_{\text{air amb}}$ is the CO_2 concentration in the ambient air (moles per unit volume).

F is the fraction of air stream CO_2 absorbed by the free OH^- ion in the supernatant.

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The absorption fraction F is given by Equation 2-4.

$$(2-4) \quad F = \frac{[CO_2]_{air_{amb}} - [CO_2]_{outlet}}{[CO_2]_{air_{amb}}}$$

Where:

$[CO_2]_{outlet}$ is the CO_2 concentration in the air stream exiting the tank.

An expression for the absorption fraction, F , is obtained using an empirical fit to measured CO_2 concentrations in the exhaust air streams of SRS H-Area waste tanks. The OH^- ion concentration of the supernatant is used to correlate the data. The correlation for the absorption fraction of CO_2 is given by Equation 2-5.

$$(2-5) \quad F = 0.165 \cdot (14 + \text{Log}(OH^-)) - 1.569$$

The absorption fraction of CO_2 from the air stream is controlled, at least in part, by the diffusion of CO_2 from the bulk air to the air-liquid interface. This mass transport process is similar to the transport of heat from the supernatant to the vapor space. Therefore, the CO_2 absorption fraction should be functionally related to heat transfer parameters, such as the ventilation flow rate and temperatures of the supernatant and vapor space. These parameters are not included in the absorption fraction term of the Hobbs empirical model.

2.3 MECHANISTIC HYDROXIDE DEPLETION MODEL

2.3.1 Model Overview

An overview of the mechanistic hydroxide depletion model is shown in Figure 2-1. CO_2 enters the vapor space through the ventilation air stream at the ambient concentration $[CO_2]_{air_{amb}}$.

There is a mass transfer of CO_2 from the bulk air to the vapor-liquid interface at a mass transfer rate of $\omega_{CO_2_{air}}$. Carbon dioxide at the vapor-liquid interface is absorbed into the liquid near the surface. The model assumes that a thin surface layer exists with species concentrations shown in Figure 2-1. The concentrations of the species CO_2 , OH^- ion, and carbonate (CO_3^{2-}) ion are related by Equations 2-1 and 2-2. Mass transfer occurs in the liquid between the surface layer and the bulk liquid as shown in Figure 2-1. The species mass transfer rates are ω_{OH^-} , ω_{CO_3} and $\omega_{CO_2_{liq}}$. From Equations 2-1 and 2-2 it can be seen that the CO_2 absorption rate from the air ($\omega_{CO_2_{air}}$) is one-half the OH^- ion depletion rate. The OH^- ion is depleted primarily at the surface. However, a small amount is depleted in the bulk liquid. The liquid-side OH^- ion and CO_2 mass transfer rates are related as shown in Equation 2-6.

$$(2-6) \quad \omega_{OH^-} = 2 \cdot \omega_{CO_2_{air}} - 2 \cdot \omega_{CO_2_{liq}}$$

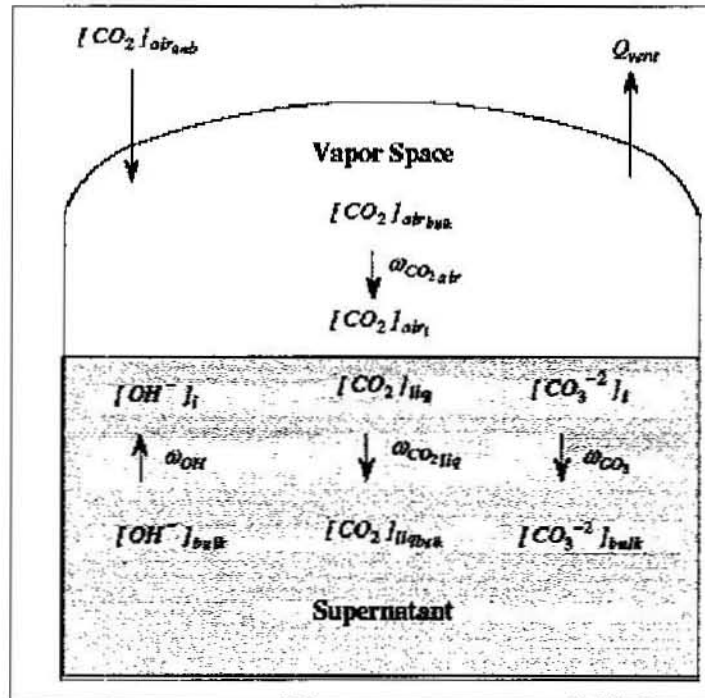
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The CO_3^{-2} ion mass transfer rate and CO_2 absorption rate are related by Equation 2-7.

$$(2-7) \quad \omega_{\text{CO}_3} = \omega_{\text{CO}_2 \text{ air}}$$

A more detailed description of the model is provided in the following sections.

Figure 2-1 Supernatant Carbon Dioxide Concentration.



2.3.2 Mass Transfer by the Colburn Analogy

2.3.2.1 Vapor Side Mass Transfer

The solution of low mass-transfer rate problems can be obtained by analogy with corresponding problems in heat transfer, *Transport Phenomenon*, (Bird et. al., 1960). The model is based upon the Colburn analogy for mass transfer, Bird et. al., 1960. The mass transfer rate is obtained by analogy to convective heat transfer. The heat transfer rate is replaced by the mass transfer rate, the heat transfer coefficient is replaced by the mass transfer coefficient and the temperature is replaced by the CO_2 mole fraction.

The CO_2 mass transfer rate from the bulk air to the air-liquid interface is given by Equation 2-8.

$$(2-8) \quad \omega_{\text{CO}_2 \text{ air}} = \Gamma_{\text{CO}_2} \cdot A_{\text{Tank}} \cdot ([CO_2]_{air,bulk} - [CO_2]_{air,i})$$

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Where:

$\omega_{CO_2,air}$ is the air-side CO₂ mass transfer rate (moles per unit time).

Γ_{CO_2} is the mass transfer coefficient (unit length per unit time).

A_{tank} is the supernatant surface area.

$[CO_2]_{air_i}$ is the CO₂ concentration at the air-side of the air/liquid interface (M).

$[CO_2]_{air,bulk}$ is the CO₂ concentration in the bulk air stream (M).

The mass transfer coefficient is obtained from the heat transfer correlation at the waste surface with the Prandtl number, from the heat transfer correlation, replaced by the Schmidt number.

The mass transfer coefficient is given by Equation 2-9.

$$(2-9) \quad \Gamma_{CO_2} = \frac{Sh \cdot D_{CO_2}}{L}$$

Where:

Sh is the Sherwood Number (Nusselt Number with Prandtl number replaced with the Schmidt number).

D_{CO_2} is the CO₂ diffusion coefficient in air.

L is the characteristic dimension which is the tank diameter for the vapor space.

The Sherwood number is obtained from the McAdams natural convection heat transfer Nusselt number for heated horizontal surfaces, Equations 2-10 through 2-12, from *Principles of Heat Transfer* (Kreith 1973).

turbulent natural convection

$$(2-10) \quad Sh = 0.14 \cdot (Gr \cdot Sc)^{\frac{1}{3}}$$

laminar natural convection

$$(2-11) \quad Sh = 0.54 \cdot (Gr \cdot Sc)^{\frac{1}{4}}$$

vapor hotter than the liquid surface

$$(2-12) \quad Sh = 0.27 \cdot (Gr \cdot Sc)^{\frac{1}{4}}$$

Where:

Gr is the Grashof number.

Sc is the Schmidt number.

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The Grashof number is defined by Equation 2-13. The Schmidt number is defined by Equation 2-14.

$$(2-13) \quad Gr = \frac{\rho_{air}^2 \cdot g \cdot \beta \cdot D_{tank}^3}{\mu^2} \cdot \Delta T$$

$$(2-14) \quad Sc = \frac{\nu}{D_{CO_2}}$$

Where:

ρ_{air} is the air density.

g is the acceleration of gravity.

β is the coefficient of thermal expansion.

D_{tank} is the characteristic length for the mass transfer (waste tank diameter).

ΔT is the temperature difference between the vapor space and the supernatant.

μ is the air viscosity.

ν is the kinematic viscosity (viscosity divided by the density) of air.

D_{CO_2} is the CO_2 diffusion coefficient in air.

2.3.2.2 Liquid Side Mass Transfer

The mass transfer for the liquid species (ω_{OH} , ω_{CO_3} and $\omega_{CO_{2liq}}$) are given by equations similar to Equations 2-8 and 2-9 where the Sherwood number is based upon the liquid diffusion coefficients and liquid properties. The characteristic dimension for the waste tanks is the assumed depth of the supernatant surface layer. The mass transfer from the surface layer of the waste tank is assumed to be limited by diffusion. The Sherwood number for diffusion is give by Equation 2-15, *Heat Transfer* (Holman 1968):

$$(2-15) \quad Sh = 1.0$$

2.3.3 Carbon Dioxide Concentration at the Air-Liquid Interface

2.3.3.1 Carbon Dioxide Concentration Air Side of Air-Liquid Interface

The CO_2 concentration at the air-liquid interface in Equation 2-8 is determined using Henry's Law, Equation 2-16, Krieth 1973.

$$(2-16) \quad P_{CO_2} = H_c \cdot [CO_2]_{liq_i}$$

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Where:

P_{CO_2} is the partial pressure of CO_2 in the air at the air-liquid interface.

H_c is Henry's Law constant.

$[CO_2]_{liq_i}$ is the concentration of CO_2 in the liquid phase in equilibrium with the gas phase.

2.3.3.2 Carbon Dioxide Concentration Liquid Side of Air-Liquid Interface

The CO_2 concentration in the supernatant is assumed to be uniform as a result of mixing by supernatant convection. The concentration near the surface is given by the equilibrium equation for CO_2 absorption. The equilibrium CO_2 absorption equation can be solved for the CO_2 concentration, Equation 2-17.

$$(2-17) \quad [CO_2]_{liq_i} = \frac{[CO_3^{-2}]_i}{[OH^-]_i^2 \cdot K_{CO_2} \cdot K_{HCO_3}}$$

Where:

$[CO_2]_{liq_i}$ is the concentration of CO_2 in the supernatant.

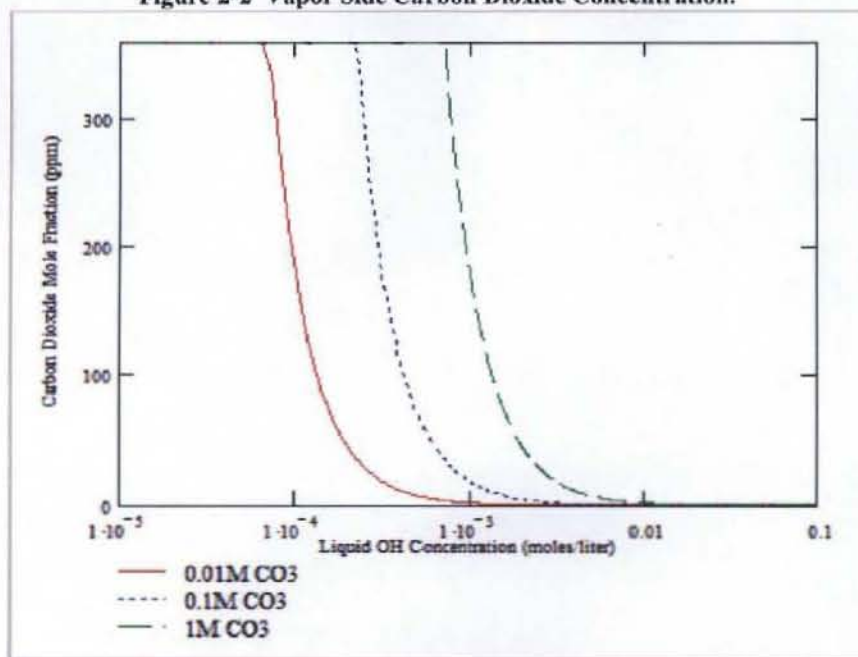
$[CO_3^{-2}]_i$ is the concentration of carbonate ion in the supernatant.

$[OH^-]_i$ is the concentration of free OH^- ion in the supernatant.

K_{CO_2} is the equilibrium constant for Equation 2-1.

K_{HCO_3} is the equilibrium constant for Equation 2-2.

Figure 2-2 Vapor Side Carbon Dioxide Concentration.



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Equations 2-16 and 2-17 can be combined to give the CO_2 concentration on the vapor-side of the air/liquid interface. The vapor-side CO_2 concentration is shown in Figure 2-2 as a function of the free OH^- ion concentration on the liquid-side vapor/liquid interface. For low OH^- ion concentrations, absorption of CO_2 approaches zero and the CO_2 concentration on the liquid side of the air-liquid interface approaches the ambient air concentration. As the free OH^- ion concentration increases, the CO_2 concentration decreases until the CO_2 concentration approaches zero.

2.3.4 Bulk Liquid Carbonate Concentrations

The CO_3^{-2} ion concentration for the bulk supernatant liquid is estimated from the predicted CO_2 absorption rate. The estimated supernatant bulk CO_3^{-2} ion molarity is given by Equation 2-18.

$$(2-18) \quad [\text{CO}_3^{-2}]_{\text{bulk}} = \frac{\text{OH}_{\text{dep}}}{2} \cdot \frac{\Delta t_{\text{tank}}}{\text{Vol}_{\text{sup}}}$$

Where:

$[\text{CO}_3^{-2}]_{\text{bulk}}$ is the molarity of CO_3^{-2} ion in the bulk supernatant (moles/liter).

OH_{dep} is the OH^- ion depletion rate (moles per unit time).

Δt_{tank} is the approximate operation time of the tank (unit time).

Vol_{sup} is the supernatant volume (unit volume).

2.3.5 Vapor Space Carbon Dioxide Bulk Concentration

The mole fraction of CO_2 in the bulk vapor space air is determined through a mass balance of CO_2 above the supernatant, Equation 2-19.

$$(2-19) \quad x_{\text{CO}_2\text{airbulk}} = x_{\text{CO}_2\text{airamb}} - \frac{\omega_{\text{CO}_2\text{air}}}{C_{\text{air}} \cdot Q_{\text{vent}}}$$

Where:

$x_{\text{CO}_2\text{airbulk}}$ is the mole fraction of CO_2 in the bulk air-stream.

$x_{\text{CO}_2\text{airamb}}$ is the mole fraction of CO_2 in the ambient air.

$\omega_{\text{CO}_2\text{air}}$ is the CO_2 mass transfer rate to the interface (mole/unit time).

Q_{vent} is the primary ventilation volumetric flow rate (volume/unit time).

C_{air} is the molarity of the ambient air (moles/ volume).

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2.3.6 Solution Methodology

The equations above are solved using Mathcad¹. The bulk air CO₂ concentration given by Equation 2-19 is a function of the mass transfer rate given by Equation 2-8, which is a function of the bulk concentration of CO₂ in the air stream. Similarly, the CO₃⁻² ion and OH⁻ ion concentrations at the liquid interface are a function of the mass transfer rate from the bulk liquid, which are a function of the interface values. An iterative solution is obtained by guessing the values of $x_{CO_2,bulk}$, $[CO_3^{-2}]_i$, and $[OH^-]_i$ and iterating until Equations 2-6, 2-7 and 2-19 are satisfied.

2.3.7 Summary of Important Physical Constants

The values for several important physical constants used in the mechanistic depletion model are given in Table 2-1.

Table 2-1 Summary of Depletion Model Constants.

Henry's Law Constant, $\frac{1}{H_c}$	4.48x10 ⁻⁵	$\frac{\text{mole}}{\text{liter mmHg}}$	Kotz, J C., Treichel, P, 1999, <i>Chemistry & Chemical Reactivity</i>
Equilibrium Constant, K_{CO_2}	3.54x10 ⁷		Appendix D
Equilibrium Constant, K_{HCO_3}	4.63x10 ³		Kotz, et al., 1999
Diffusion Coefficient, $D_{CO_2,air}$	0.64	$\frac{ft^2}{hr}$	Krieth 1973
Diffusion Coefficient, $D_{CO_2,liq}$	6.9x10 ⁻⁵	$\frac{ft^2}{hr}$	Krieth 1973
Diffusion Coefficient, $D_{OH,liq}$	2.05x10 ⁻⁴	$\frac{ft^2}{hr}$	MacInnes, D, 1961, <i>The Principles of Electrochemistry</i>
Diffusion Coefficient, $D_{CO_3,liq}$	2.7x10 ⁻⁵	$\frac{ft^2}{hr}$	Zaytsev, I, Ascyev, G., 1992, <i>Properties of Aqueous Solutions of Electrolytes</i>

3.0 HYDROXIDE DEPLETION DATA

Measured data related to OH⁻ ion depletion for both SRS and Hanford Site waste tanks is used to benchmark the hydroxide depletion models presented in Section 2.0. Data used for the benchmark of the depletion models are presented in this section.

3.1 HOBBS CARBON DIOXIDE ABSORPTION DATA

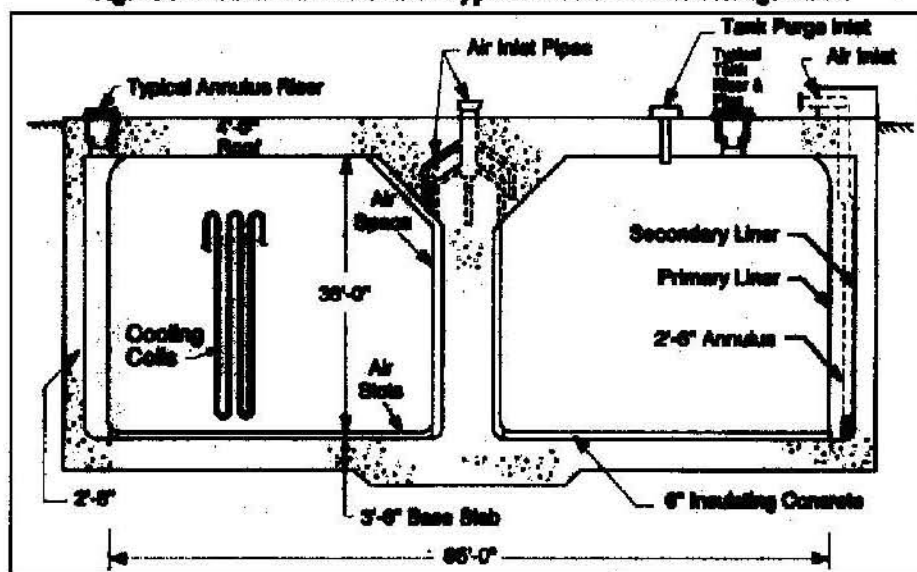
A program was conducted in 1986 and 1987 at the SRS to determine the mechanism and rate of OH⁻ ion depletion through CO₂ absorption, DPST-87-596. The program was conducted for

¹ Mathcad is a register trade mark of MathSoft, Inc, Cambridge, Ma.

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H-Area waste tanks. A model was developed from the data obtained which predicted the time dependent inhibitor concentration in solution for the H-Area waste tanks. A schematic of a H-Area waste tank is shown in Figure 3-1. The tank design differs from the Hanford Site DSTs. There are several important features to note for the OH^- ion depletion study. The waste tank diameter is 85 ft, 10 ft larger than the Hanford Site DSTs. Both the SRS H-Area tanks and the Hanford Site DSTs are purged or ventilated to prevent the build-up of flammable gases. This air-stream provides continuous availability of CO_2 which is partially absorbed through chemical reactions with the free OH^- ion in the supernatant.

Figure 3-1 Savannah River Site Type III Cooled Waste Storage Tank.



The program to evaluate CO_2 absorption measured the primary tank ventilation air flow rates, the inlet and outlet CO_2 concentrations in the ventilation air streams and the supernatant pH. The four parameters were monitored over roughly a one-year period for the eight H-Area tanks shown in Table 3-1. The CO_2 absorption fraction from the ventilation air stream was computed based upon the measured CO_2 concentrations using Equation 2-4.

A summary of the measured inlet CO_2 concentrations, primary ventilation flow rates, average supernatant temperatures, computed absorption fractions and supernatant pH measurements are shown Table 3-1. The free OH^- ion concentration is computed from the pH, also shown in Table 3-1. Table 3-1 data are reported in DPST-87-596, from the SRS study.

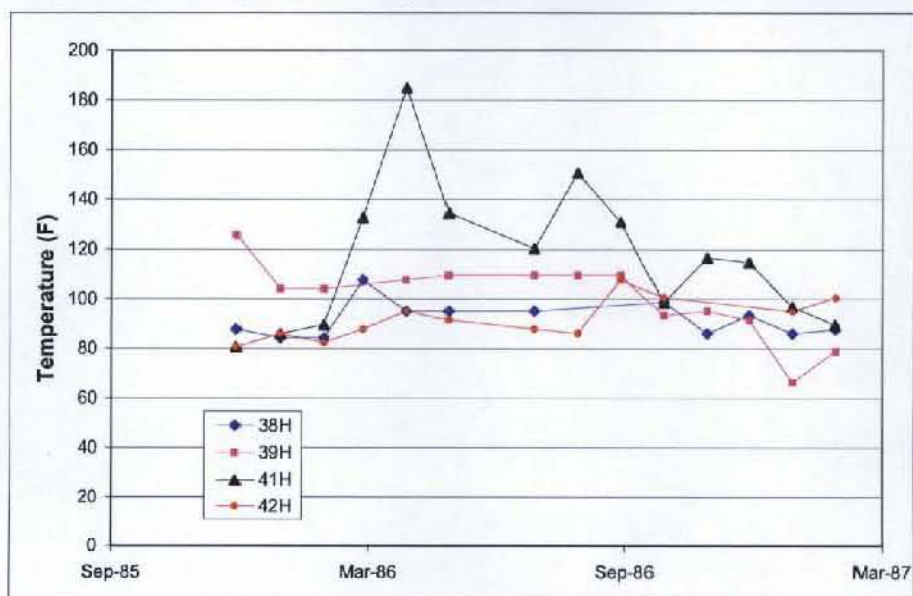
The supernatant temperatures for each tank are shown in Figures 3-2 and 3-3. Vapor space temperatures were not available. The average temperature difference between the vapor space and supernatant for selected Hanford Site waste tanks is used for the SRS tanks. The average temperature difference used for the SRS data is presented in Section 3.2.

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Table 3-1 Savannah River Site Data Summary.

Tank	Inlet [CO ₂] (ppm)	Ventilation Flow Rate (cfm)	Average Supernatant Temperature (°F)	CO ₂ Absorption Fraction	pH	[OH] ²
38H	359	268	92	0.80	14	1.00
39H	360	264	100	0.79	14	1.00
41H	366	351	116	0.76	14.8	6.31
42H (high OH ⁻)	364	430	91	0.58	13.1	0.13
42H (low OH ⁻)	355	430	91	0.10	10	0.0001
43H	361	311	139	0.83	14.4	2.51
48H (high OH ⁻)	350	266	109	0.72	13.4	0.25
48H (low OH ⁻)	361	231	109	0.40	12.8	0.06
49H	357	336	82	0.70	13.6	0.40
50H	362	293	82	0.75	13.8	0.63

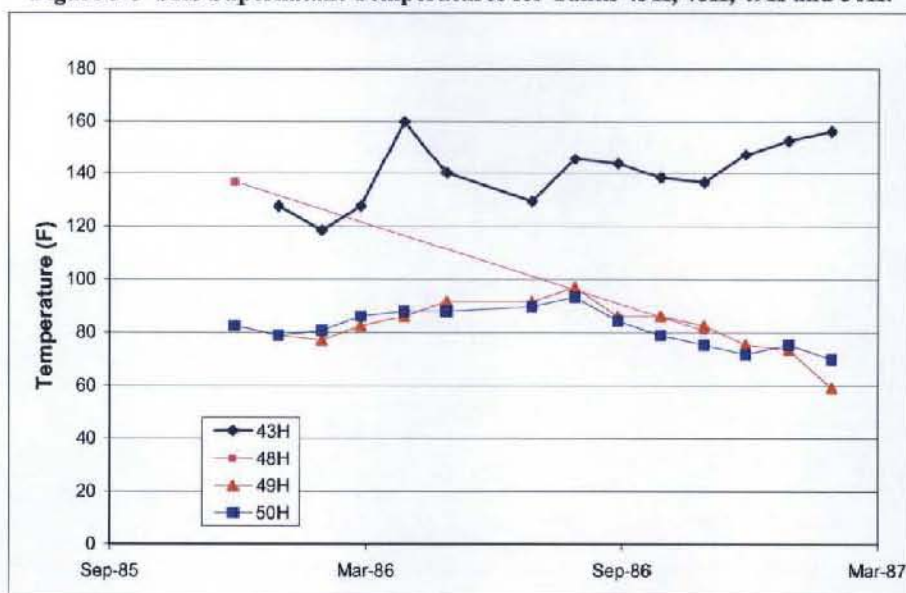
Figure 3-2 SRS Supernatant Temperatures for Tanks 38H, 39H, 41H and 42H.



² OH⁻ concentration derived from pH (pH = 14 + Log[OH⁻]).

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Figure 3-3 SRS Supernatant Temperatures for Tanks 43H, 48H, 49H and 50H.



3.2 HANFORD SITE HYDROXIDE DEPLETION DATA

Supernatant OH⁻ ion concentration and waste volume data have been evaluated for the twenty-eight Hanford Site DSTs to identify suitable data for benchmarking the mechanistic hydroxide depletion model. The evaluation identified ten waste tanks with useful data for the depletion model benchmark. The tanks included in the benchmark using the supernatant OH⁻ ion concentration data are identified below.

1. 241-AN-104
2. 241-AN-105
3. 241-AP-101
4. 241-AP-103
5. 241-AW-103
6. 241-AW-105
7. 241-AY-101
8. 241-AY-102
9. 241-AZ-101
10. 241-AZ-102

This list includes tanks from all the DST tank farms with the exception of the 241-SY Farm.

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The following parameters are needed for the mechanistic OH⁻ depletion model presented in Section 2.3:

- Primary tank ventilation flow rate,
- OH⁻ ion concentration,
- Supernatant volume, and
- Supernatant and vapor space temperature difference.

Data for the OH⁻ ion concentrations, tank waste volumes, and waste temperatures have been obtained from the Tank Waste Information Network System (TWINS). Settled solids waste volumes, needed to determine supernatant volumes from the tank waste volumes, are obtained from the sources listed in each tank-specific section. The primary tank ventilation flow rates have been obtained from sources identified in each of the sections.

Table 3-2 summarizes the data needed for the mechanistic hydroxide depletion model benchmark. The waste tanks included in the mechanistic depletion model benchmark represent the Hanford Site DSTs in terms of population size, waste type and variation of the parameters listed above and shown in Table 3-2.

Table 3-2 Hanford Site Data Summary.

Tank 241-	Primary Ventilation Flow Rate (cfm)	Assumed Initial OH⁻ Concentration (M)	Average Supernatant Volume During Evaluation Period (kgal)	Vapor Space Temperature Difference (°F)	Derived OH⁻ Depletion Rate (M/yr)
AN-104	132	3.9	607	2.3	0.009
AN-105	132	3.7	588	2.3	0.028
AP-101	111	2.4	1113	0.01	0.013
AP-103	111	0.53	282	0.01	0.020
AW-103	139	0.80	786	0.05	0.013
AW-105	139	0.27	158	-0.01	0.004
AY-101	340	1.9	86	9.0	0.41
AY-102a	425	0.51	435	4.0	0.12
AY-102b	425	0.95	488	3.1	0.11
AZ-101	149	0.81	864	2.0	0.016
AZ-102 (period 1)	102	0.02	857	2.0	0.004
AZ-102 (period 2)	102	0.15	891	2.0	0.014

The table includes the free OH⁻ ion molarity depletion rate. These values have been derived from the measured supernatant OH⁻ ion concentration data and are further discussed in Section 3.2.1 through 3.2.11. The differences between vapor space and supernatant temperatures are shown in Table 3-2. The average temperature differences for the Hanford Site tanks shown in Table 3-2 were used for the SRS data evaluation. The average temperature difference is 2.2 °F.

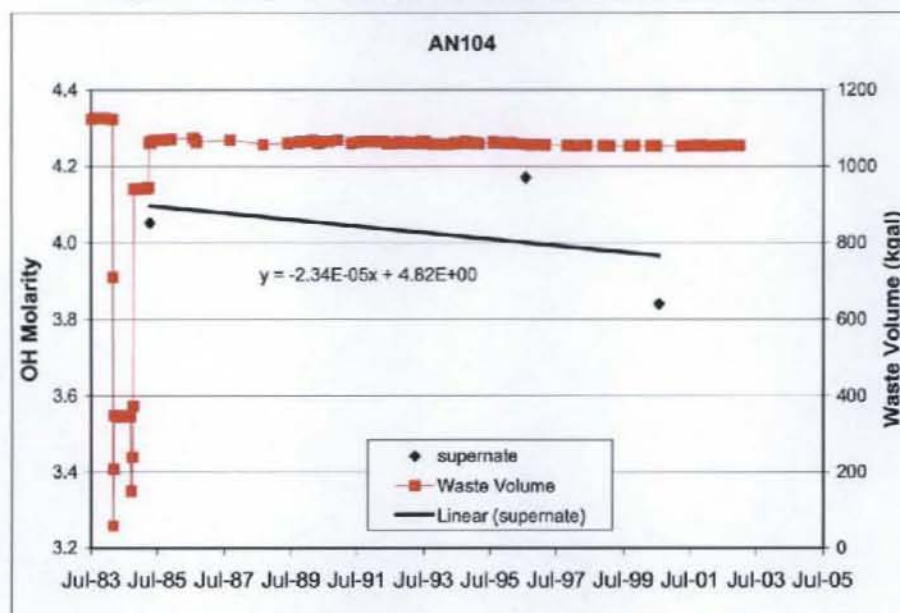
3.2.1 Tank 241-AN-104

The OH⁻ ion depletion for Tank 241-AN-104 is evaluated for approximately fifteen years, between April 1985 to July 2000. The tank waste volume and measured supernatant OH⁻ ion concentrations are shown in Figure 3-4 (TWINS 2005). The measured OH⁻ ion concentration

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data are summarized in Table 3-3. The tank volume during the evaluation period is nearly constant at 1052 kgal. This tank contains 445 kgal of saltcake solid waste, HNF-EP-0182, Rev 220, *Waste Tank Summary Report for Month Ending July 31, 2006*. The supernatant volume during the evaluation period, by difference, is 607 kgal.

Figure 3-4 Tank 241-AN-104 Hydroxide Ion Concentration Data.



The OH⁻ ion concentrations shown on Figure 3-4 represent the calculated supernatant composition in April 1985, after the tank received slurry waste from two evaporator campaigns, and mid-point values of the other two sample events. The initial value at the beginning of the evaluation period is 4.05 M, RPP-26737, *Tank 241-AN-104 Supernatant and Interstitial Liquid Hydroxide Concentration*. An average value of 3.9 M is used for the evaluation. A linear regression of the OH⁻ ion concentration data provides an estimate of the OH⁻ ion depletion rate for the evaluation period. The OH⁻ ion depletion rate is approximately 0.009 M/yr. The maximum rate based upon the ventilation flow rate, with 100% CO₂ absorption, is 0.028 M/yr.

The vapor space and supernatant temperature trends are shown in Figure 3-5 (TWINS 2005). The average temperature difference between the vapor space and supernatant is 8.3 °F. The April 2005 temperature profile in Figure 3-6 shows the large temperature drop across the liquid-air interface. This temperature difference is significantly larger than the 2.3 °F temperature difference in Tank 241-AN-103, Figure 3-7. The ventilation flow rates for Tanks 241-AN-103 and 241-AN-104 are both estimated to be 132 cfm, (Section 4.3.11, Table 4-14). The estimated annulus ventilation flow rates are also the same, RPP- 12422, *Engineering Evaluation of Double-Shell Tank Vapor Space Condensation and Annulus Relative Humidity*. The tank heat loads are similar. Tank 241-AN-103 has a heat load of 30,200 Btu/hr while Tank 241-AN-104's heat load is 34,100 Btu/hr, RPP-5926, *Steady-State Flammable Gas Release Rate Calculation and Lower Flammability Level Evaluation for Hanford Tank Waste*. Since the heat generation for the two tanks is similar and the heat removal through primary and annulus ventilation is the same, the temperature differences should be very similar. The high temperature difference for

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Tank 241-AN-104 may be an indication of a non-convective waste layer (crust) near the surface of the supernatant. The supernatant/vapor space temperature difference for Tank 241-AN-103 will be used for the evaluation, since the actual temperature difference between the liquid at the surface of the waste (top of the non-convective layer) and the vapor space is expected to be closer to 2.3 °F.

The mass transfer through the crust is modeled with a crust thickness and porosity. Mass transfer is assumed to occur by diffusion only. The crust thickness is approximately 20 in as shown in Figure 3-6. An empirical value of 0.02 for the porosity was determined from the evaluation of Tank 241-SY-101, Section 4.3.5. This value provides reasonable agreement with the CO₂ data for Tank 241-SY-101. This same value is then used for all tanks with a surface crust. This empirical approach provides a reasonable prediction of the OH⁻ ion depletion rate for the limited number of tanks with surface crusts.

Table 3-3 Tank 241-AN-104 Measured Hydroxide Concentrations.

Sample Event Begin Date	OH ⁻ Molarity	Sampling Event Type	Segment	Phase	Source Document
September 1984	4.6	Slurry Set 84-5, Liquid Phase, Sample R-3303	n/a	Supernatant	Internal Letter, 65453-84-349
September/October 1984	4.72	Slurry Set 84-5, Liquid Phase, Sample R3305	n/a	Supernatant	Internal Letter 65453-85-009
September/October 1984	4.03	Slurry Set 84-5, Liquid Phase, Sample R3307	n/a	Supernatant	Internal Letter, 65453-85-009
September/October 1984	3.73	Slurry Set 84-5, Liquid Phase, Sample R3413	n/a	Supernatant	Internal Letter, 65453-85-009
September/October 1984	3.48	Slurry Set 84-5, Liquid Phase, Sample R3415	n/a	Supernatant	Internal Letter, 65453-85-009
April 1985	4.48	Slurry Set 85-3, Liquid Phase, Sample R4683	n/a	Supernatant	Internal Letter 65453-85-160
April 1985	3.38	Slurry Set 85-3, Liquid Phase, Sample R4687	n/a	Supernatant	Internal Letter, 65453-85-160
August 1996	4.14	Core 164	Composite	Supernatant	HNF-SD-WM-DP-226
August 1996	4.20	Core 164	Composite	Supernatant	HNF-SD-WM-DP-226
July/August 2000	3.66	Core 282	1	Supernatant	FH-0201779
July/August 2000	4.02	Core 282	1	Supernatant	FH-0201779

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Figure 3-5 Tank 241-AN-104 Temperature Data.

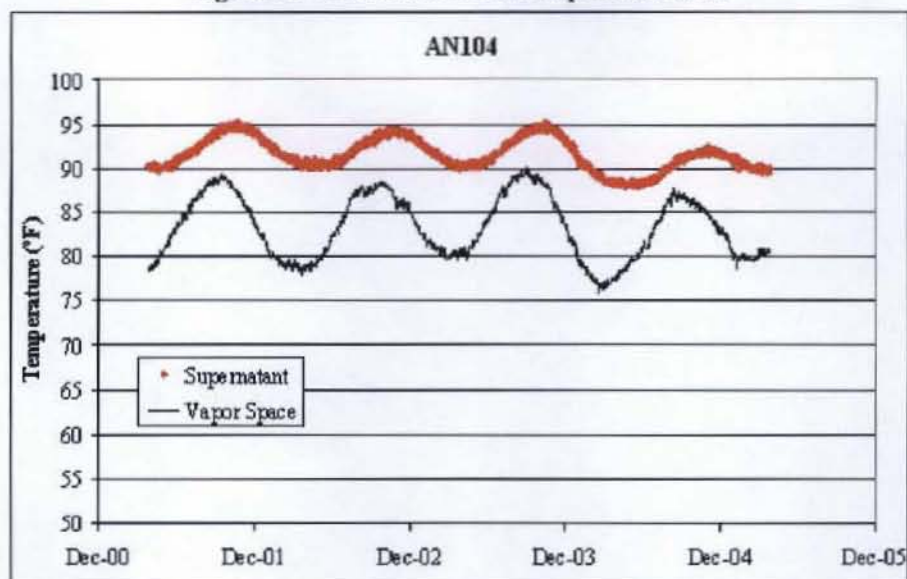
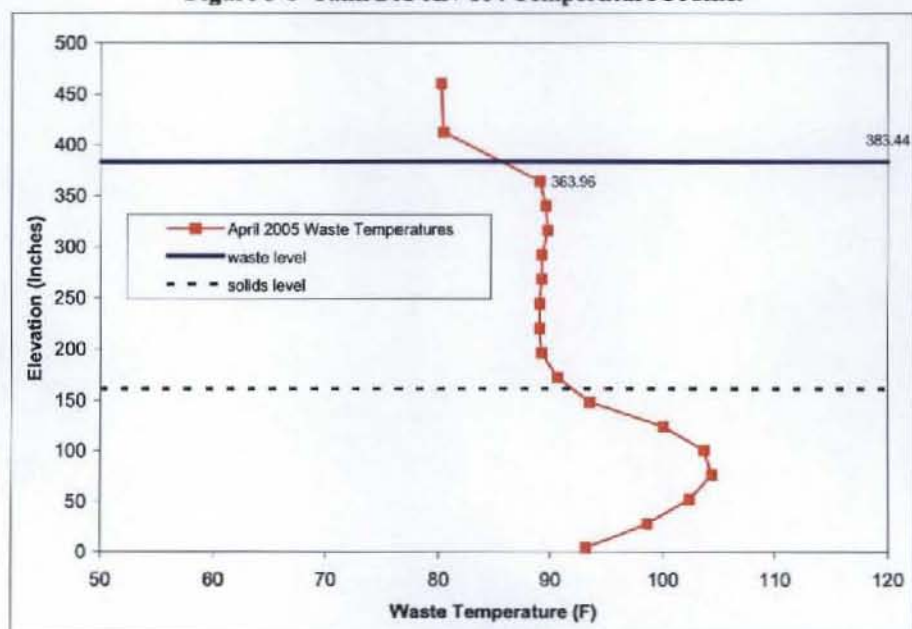
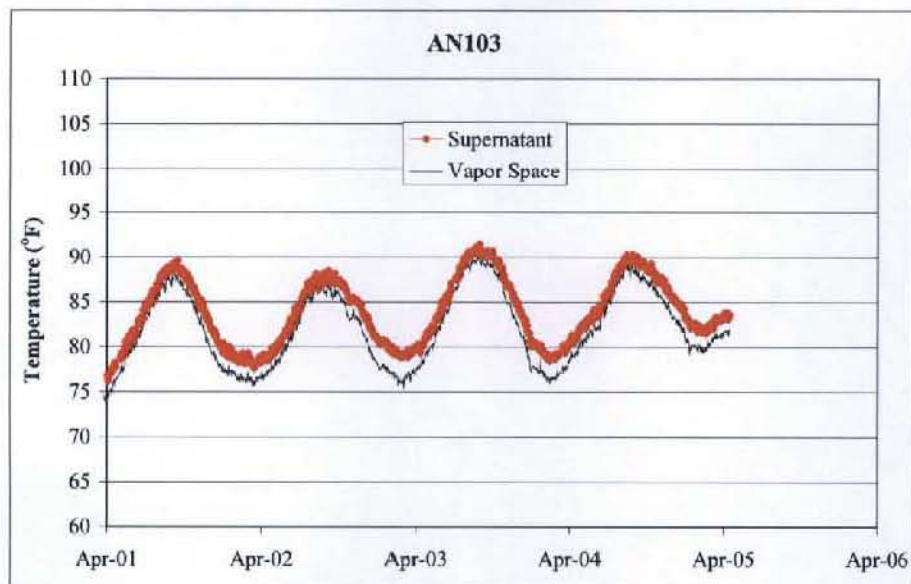


Figure 3-6 Tank 241-AN-104 Temperature Profile.



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Figure 3-7 Tank 241-AN-103 Temperature Data.



3.2.2 Tank 241-AN-105

The OH^- ion depletion for Tank 241-AN-105 is evaluated for approximately a seventeen-year period between April 1985 and December 2001. The tank waste volume and measured supernatant OH^- ion concentrations are shown in Figure 3-8 (TWINS 2005). The measured OH^- ion concentration data are summarized in Table 3-4. The tank volume during the evaluation period is nearly constant at 1126 kgal. This tank contains 538 kgal of saltcake solid waste, HNF-EP-0182, Rev. 220. The supernatant volume, by difference, is 588 kgal during the evaluation period.

The OH^- ion concentrations shown in Figure 3-8 represent the mid-point for all the data obtained for the three sample events listed in Table 3-4. The average value for the evaluation period is 3.7 M. A linear regression of the OH^- ion concentration data provides an estimate of the OH^- ion depletion rate for the evaluation period. The OH^- ion depletion rate is approximately 0.028 M/yr. The maximum rate based upon the ventilation flow rate, with 100% CO_2 absorption, is 0.028 M/yr.

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Figure 3-8 Tank 241-AN-105 Hydroxide Ion Concentration Data.

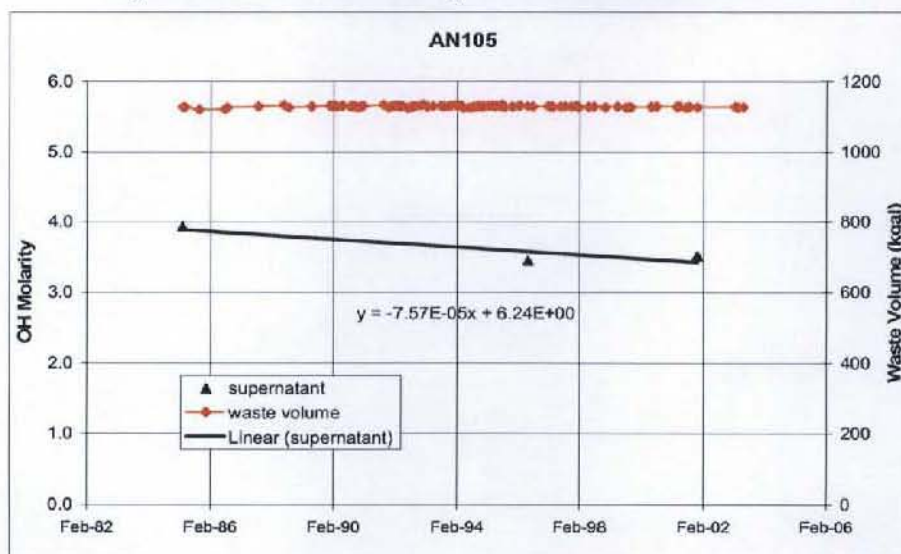


Table 3-4 Tank 241-AN-105 Measured Hydroxide Concentrations.

Aggregation Level	Sample Event Date	Reported Value (µg/ml)	Reported Value (M)	Average Values (M)	Sampling Event Name	Segment Name	Location of Document
Supernatant (Slurry Filtrate)	4/3/85	-	4.480	3.93	Slurry Set 85-3, Liquid Phase, Sample R-4683	NA	SD-WM-PE-023, Rev 0, Internal Letter 65453-85-160 (pages 33-44)
Supernatant (Slurry Filtrate)	4/10/85	-	3.380		Slurry Set 85-3, Liquid Phase, Sample R-4687	NA	SD-WM-PE-023, Rev 0, Internal Letter 65453-85-160 (pages 33-44)
Core Composite	6/10/96	60500	-	3.44	Core 152	1 -14	HNF-SD-WM-DP-199, Rev. 1
Core Composite	6/10/96	56600	-		Core 152	1 -14	HNF-SD-WM-DP-199, Rev. 1
Drainable Liquid	12/12/01	56500	-	3.51	298	1	FH-0200808 Reissue 1

The vapor space and supernatant temperature trends are shown in Figures 3-9 (TWINS 2005). The average temperature difference between the vapor space and supernatant shown in Figure 3-9 exceeds 10 °F. The December 2005 temperature profile in Figure 3-10 shows the large temperature drop across the liquid-air interface. This temperature difference is inconsistent with the tank heat load in RPP-5926 of 25,100 Btu/hr; especially since the Tank 241-AN-103 heat load is 30,200 Btu/hr with a supernatant and vapor space temperature difference of 2.3 °F. The large temperature difference is probably due to a non-convective (crust) layer near the surface of the supernatant. Because Tank 241-AN-105 has a similar tank heat load and ventilation flow rate as Tank 241-AN-103, the average vapor space/supernatant temperature difference of 2.3 °F for Tank 241-AN-103 is used for Tank 241-AN-105.

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The mass transfer through the crust is modeled with a crust thickness and porosity. Mass transfer is assumed to occur by diffusion only. The crust thickness is approximately 20 in. (Section 3.1.2, Appendix B). An empirical value of 0.02 for the crust porosity was determined from the evaluation of Tank 241-SY-101, Section 4.3.5. This value provides reasonable agreement with the CO₂ data for Tank 241-SY-101. This same value is then used for all tanks with a surface crust with the exception of Tank 241-SY-103 discussed in Section 4.3.7. This empirical approach provides a reasonable prediction of the OH⁻ ion depletion rate for the limited number of tanks with surface crusts.

Figure 3-9 Tank 241-AN-105 Temperature.

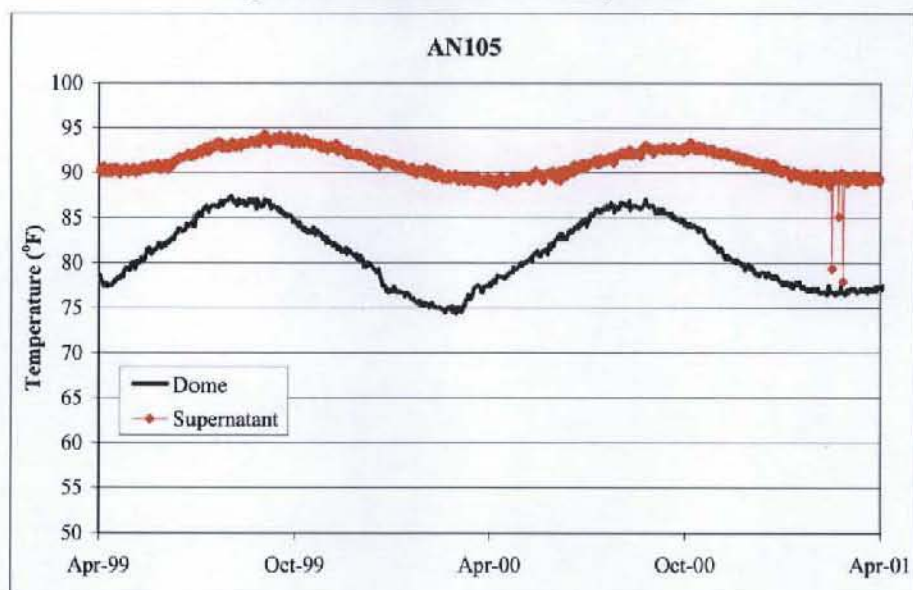
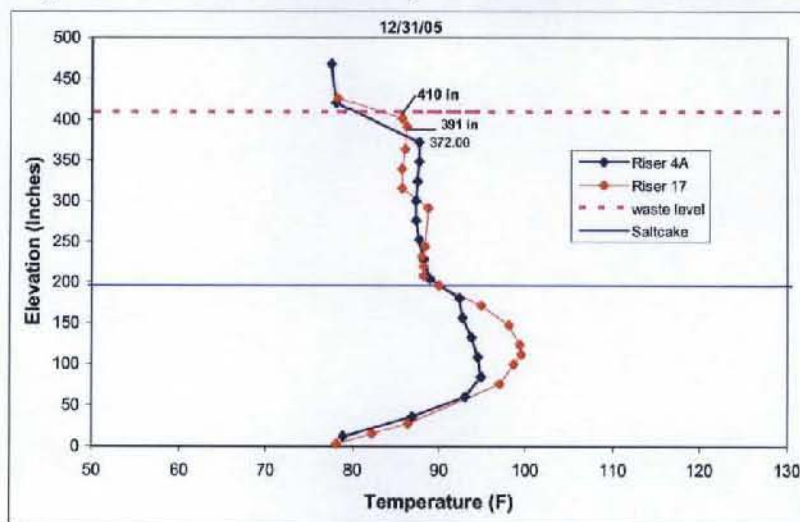


Figure 3-10 Tank 241-AN-105 Temperature Profile for December 2005.



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The estimated primary tank ventilation flow rate for Tank 241-AN-105 is 132 cfm, (Section 4.3.11, Table 4-14). This ventilation flow rate includes filtered inlet flow and in-leakage.

3.2.3 Tank 241-AP-101

The OH⁻ ion depletion for Tank 241-AP-101 is evaluated for approximately a four-year period between February 2000 and April 2004. The tank waste volume and measured supernatant OH⁻ ion concentrations are shown in Figure 3-11 (TWINS 2007). The measured OH⁻ ion concentration data are summarized in Table 3-5. The tank volume during the evaluation period is nearly constant at 1113 kgal. This tank contains no settled solids, HNF-EP-0182, Rev. 220.

The average OH⁻ ion concentration for the evaluation period, February 2000, is 2.39 M. A linear regression of the OH⁻ ion concentration data provides an estimate of the OH⁻ ion depletion rate for the evaluation period. The OH⁻ ion depletion rate is approximately 0.022 M/yr. The maximum rate based upon the ventilation flow rate, with 100% CO₂ absorption, is 0.013 M/yr. Because of uncertainty in the OH⁻ ion concentration data and the primary tank ventilation flow rate, the computed maximum for the assumed ventilation flow rate will be used.

Figure 3-11 Tank 241-AP-101 Hydroxide Ion Concentration Data.

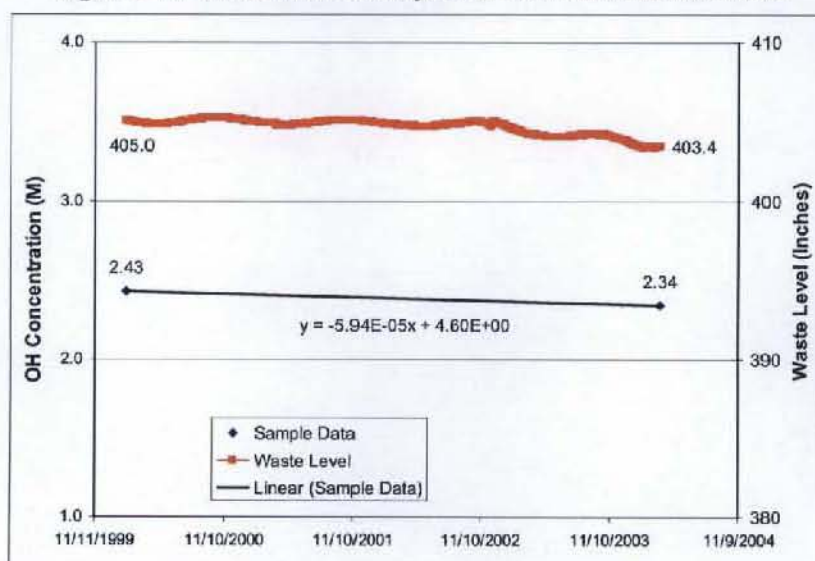


Table 3-5 Tank 241-AP-101 Measured Hydroxide Concentrations.

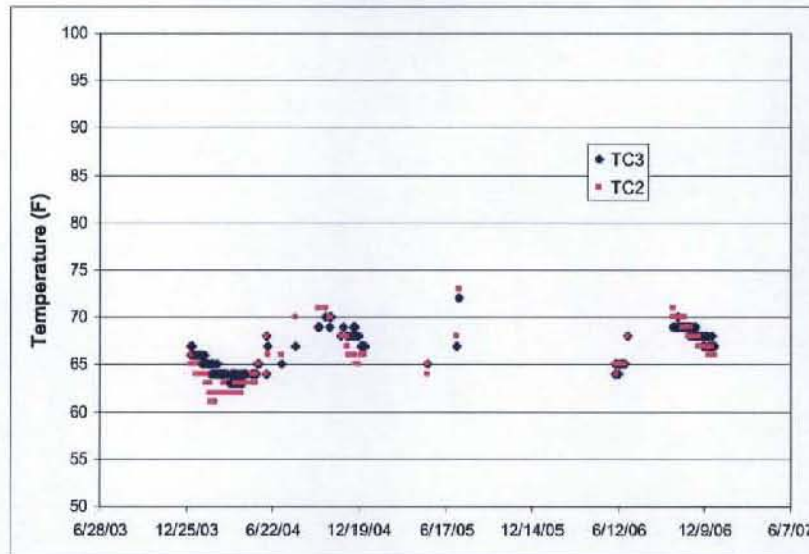
Tank Name	Constituent Name	Sample Event Begin Date	OH Concentration (M)	Location of Document
241-AP-101	Hydroxide	2/8/2000	2.43	RPP-13639, Rev 0
241-AP-101	Hydroxide	4/1/2004	2.34	RPP-13639, Rev 2

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Vapor space and supernatant temperatures are shown in Figure 3-12 (TWINS 2007). The average temperature difference between the vapor space and supernatant shown in Figure 3-12 is small. A value of 0.01 °F is used for the evaluation.

The estimated primary tank ventilation flow rate for Tank 241-AP-101 is 111 cfm, RPP-29806, *Evaluation of Tank 241-AP-105 Supernatant and Interstitial Liquid Hydroxide Concentration*.

Figure 3-12 Tank 241-AP-101 Temperature.



3.2.4 Tank 241-AP-103

The OH⁻ ion depletion for Tank 241-AP-103 is evaluated for a three-year period from August 1999 to October 2002. The tank waste volume and measured supernatant OH⁻ ion concentrations are shown in Figure 3-13 (TWINS 2005). The measured OH⁻ ion concentration data are summarized in Table 3-6. The tank volume during the evaluation period is nearly constant at 282 kgal. This tank does not contain any solid waste, HNF-EP-0182, Rev. 220. The supernatant volume during the evaluation period is 282 kgal.

The OH⁻ ion concentrations shown in Figure 3-13 represent the mid-points for the data shown in Table 3-6. The average value for the evaluation period is 0.53 M. A linear regression of the OH⁻ ion concentration data provides an estimate of the OH⁻ ion depletion rate for the evaluation period. The OH⁻ ion depletion rate is approximately 0.02 M/yr. The maximum rate based on the ventilation flow rate, with 100% CO₂ absorption, is 0.031 M/yr.

Vapor space and supernatant temperatures are shown in Figure 3-14 (TWINS 2005). The average temperature difference between the vapor space and supernatant shown in Figure 3-10 is small. The temperature difference is very small during the period and difficult to quantify. A small value of 0.01°F is used for the evaluation. This temperature difference is consistent with the tank heat load of 13,600 Btu/hr, RPP-5926.

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The estimated primary tank ventilation flow rate for Tank 241-AP-103 is 111 cfm, RPP-29806.

Figure 3-13 Tank 241-AP-103 Hydroxide Ion Concentration Data.

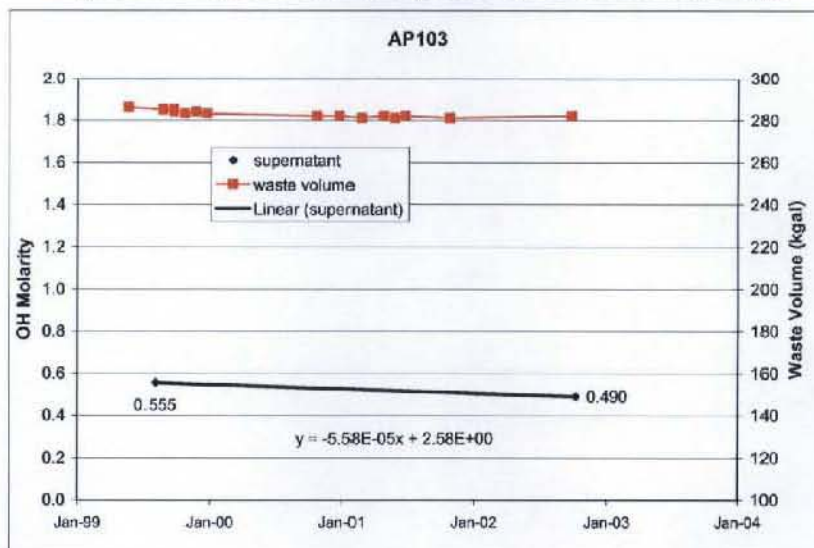
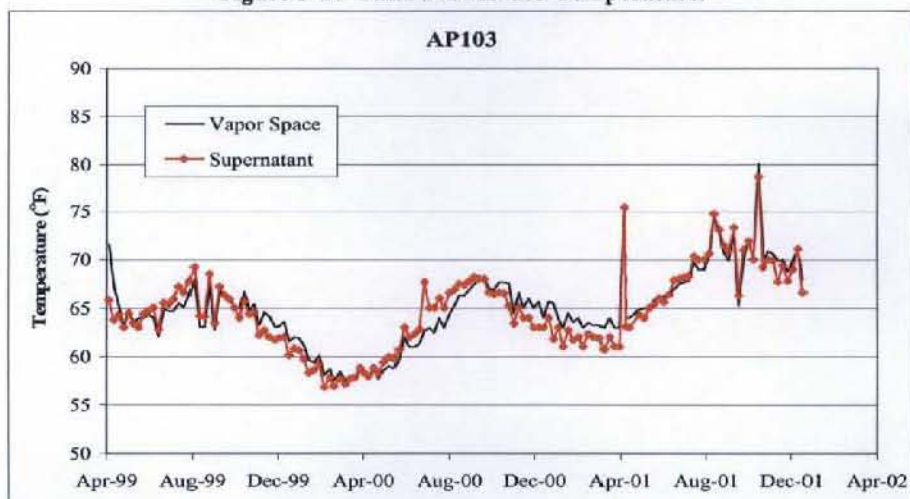


Table 3-6 Tank 241-AP-103 Measured Hydroxide Concentrations.

Sample Event Begin Date	OH ⁻ Molarity	Sampling Event Type	Segment	Phase	Source Document
August 1999	0.52	Grab Sample	n/a	Supernatant	HNF-1683 Rev. 0
August 1999	0.55	Grab Sample	n/a	Supernatant	HNF-1683 Rev. 0
August 1999	0.56	Grab Sample	n/a	Supernatant	HNF-1683 Rev. 0
August 1999	0.56	Grab Sample	n/a	Supernatant	HNF-1683 Rev. 0
August 1999	0.58	Grab Sample	n/a	Supernatant	HNF-1683 Rev. 0
August 1999	0.59	Grab Sample	n/a	Supernatant	HNF-1683 Rev. 0
October 2002	0.47	Grab Sample	n/a	Supernatant	FH-0205804
October 2002	0.51	Grab Sample	n/a	Supernatant	FH-0205804

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Figure 3-14 Tank 241-AP-103 Temperature.

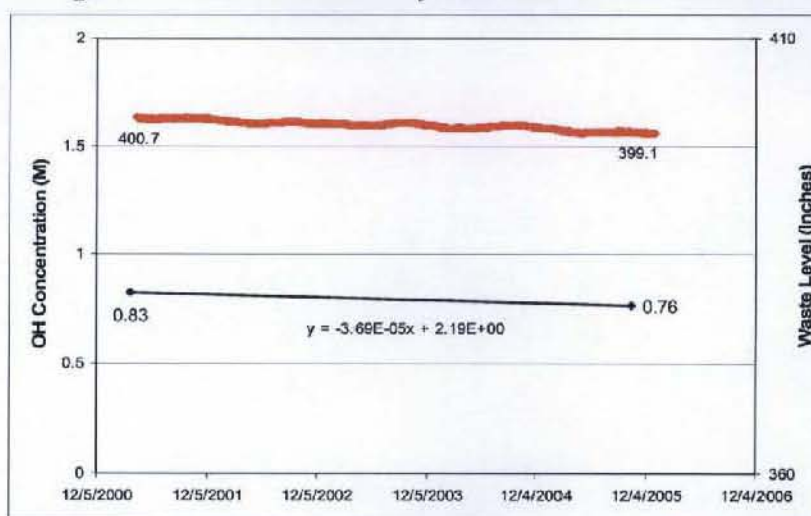


3.2.5 Tank 241-AW-103

The OH^- ion depletion for Tank 241-AW-103 is evaluated for approximately a four and one half year period between April 2001 and October 2005. The tank waste volume and measured supernatant OH^- ion concentrations are shown in Figure 3-15 (TWINS 2007). The measured OH^- ion concentration data are summarized in Table 3-7. The tank volume during the evaluation period is nearly constant at approximately 1100 kgal. This tank contains 273 kgal of sludge and 40 kgal of saltcake, HNF-EP-0182, Rev. 220. The supernatant volume by difference is approximately 786 kgal.

The average OH^- ion concentration for the evaluation period is 0.8 M. A linear regression of the OH^- ion concentration data provides an estimate of the OH^- ion depletion rate for the evaluation period. The OH^- ion depletion rate is approximately 0.013 M/yr. The maximum rate based upon the ventilation flow rate, with 100% CO_2 absorption, is 0.022 M/yr.

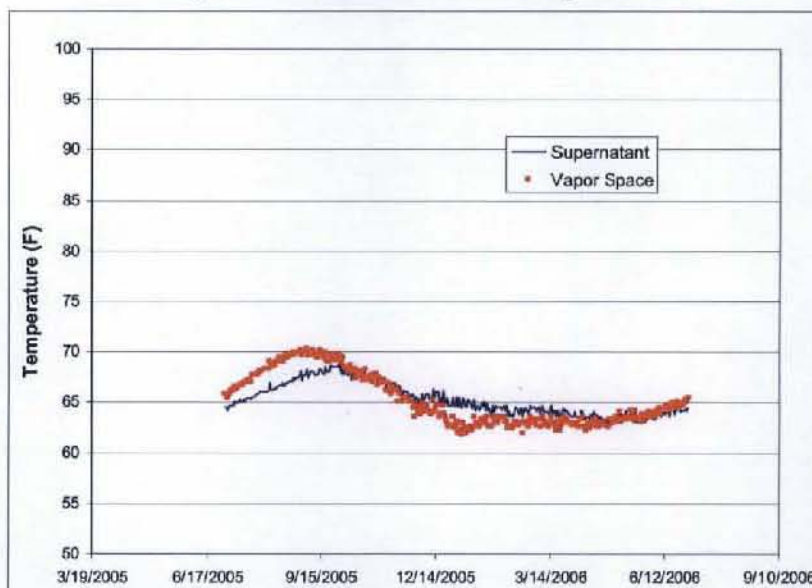
Figure 3-15 Tank 241-AW-103 Hydroxide Ion Concentration Data.



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Table 3-7 Tank 241-AW-103 Measured Hydroxide Concentrations.

Sample Event Begin Date	Reported Value ($\mu\text{g/mL}$)	OH Concentration (M)	Sampling Event Name	Segment Name	Location of Document
3/27/2001 ³		0.826			RPP-13639, Rev 1
10/14/2005	13000	0.764	320	1	06-ATL-012

Figure 3-16 Tank 241-AW-103 Temperature.

Vapor space and supernatant temperatures are shown in Figure 3-16 (TWINS 2007). The average temperature difference between the vapor space and supernatant shown in Figure 3-16 is small. An average value of 0.05 °F is used for the evaluation.

The estimated primary tank ventilation flow rate for Tank 241-AW-103 is 139 cfm, (see Table 4-7).

3.2.6 Tank 241-AW-105

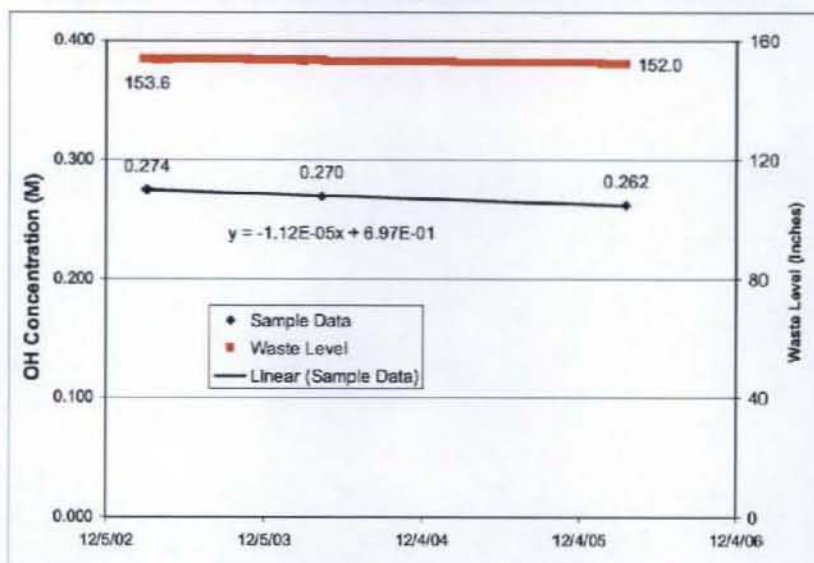
The OH⁻ ion depletion for Tank 241-AW-105 is evaluated for approximately a four and one half year period between March 2003 and March 2006. The tank waste volume and measured supernatant OH⁻ ion concentrations are shown in Figure 3-17 (TWINS 2007). The measured OH⁻ ion concentration data are summarized in Table 3-8. The tank volume during the evaluation period is nearly constant at approximately 420 kgal. This tank contains 263 kgal of sludge, HNF-EP-0182, Rev. 220. The supernatant volume by difference is approximately 158 kgal.

³ Inventory date, which is the sample date of the waste source contributing the majority of the OH⁻ ion in the supernatant.

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The average OH^- ion concentration for the evaluation period is 0.27 M. A linear regression of the OH^- ion concentration data provides an estimate of the OH^- ion depletion rate for the evaluation period. The OH^- ion depletion rate is approximately 0.004 M/yr. The maximum rate based upon the ventilation flow rate, with 100% CO_2 absorption, is 0.058 M/yr.

Figure 3-17 Tank 241-AW-105 Hydroxide Ion Concentration Data.

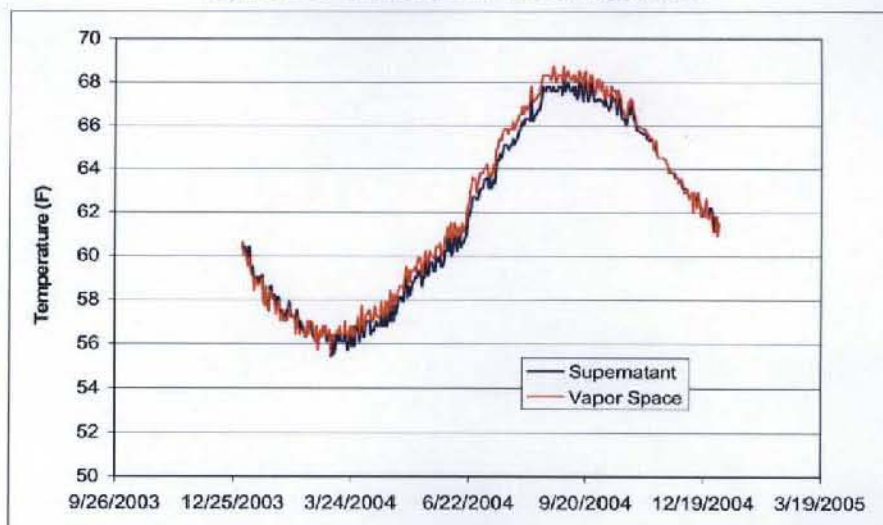


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Table 3-8 Tank 241-AW-105 Measured Hydroxide Concentrations.

Sample Event Begin Date	Aggregation Level	Reported Value (µg/mL)	Average Concentration (M)	Sampling Event Name	Segment Name	Location of Document
3/7/2003	Grab Sample	4860	0.274	5AW-03-01A	NA	FH-0301675
3/7/2003	Grab Sample	4830		5AW-03-01A	NA	FH-0301675
3/7/2003	Grab Sample	4390		5AW-03-01B	NA	FH-0301675
3/7/2003	Grab Sample	4590		5AW-03-01B	NA	FH-0301675
4/16/2004	Grab Sample	4270	0.273	5AW-04-01	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	4310		5AW-04-01	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	4850		5AW-04-01	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	4890		5AW-04-01	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	4430		5AW-04-01	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	4540		5AW-04-01	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	4820		5AW-04-02	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	4720		5AW-04-02	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	4430		5AW-04-02	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	4510		5AW-04-02	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	4260		5AW-04-02	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	4390		5AW-04-02	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	4530		5AW-04-03	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	4530		5AW-04-03	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	5090		5AW-04-03	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	5630		5AW-04-03	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	4690		5AW-04-03	NA	7S120-SGM-04-015
4/16/2004	Grab Sample	4770		5AW-04-03	NA	7S120-SGM-04-015
3/21/2006	Drainable Liquid	4440	0.262	322	1	RPP-RPT-29745 Rev.0
3/21/2006	Drainable Liquid	4470		322	1	RPP-RPT-29745 Rev.0

Figure 3-18 Tank 241-AW-105 Temperature.



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Vapor space and supernatant temperatures are shown in Figure 3-18 (TWINS 2007). The average temperature difference between the vapor space and supernatant shown in Figure 3-18 is small. The vapor space temperature exceeds the supernatant temperature for much of the data. The temperature differences are very small and difficult to quantify. A value of -0.01°F is used for the evaluation.

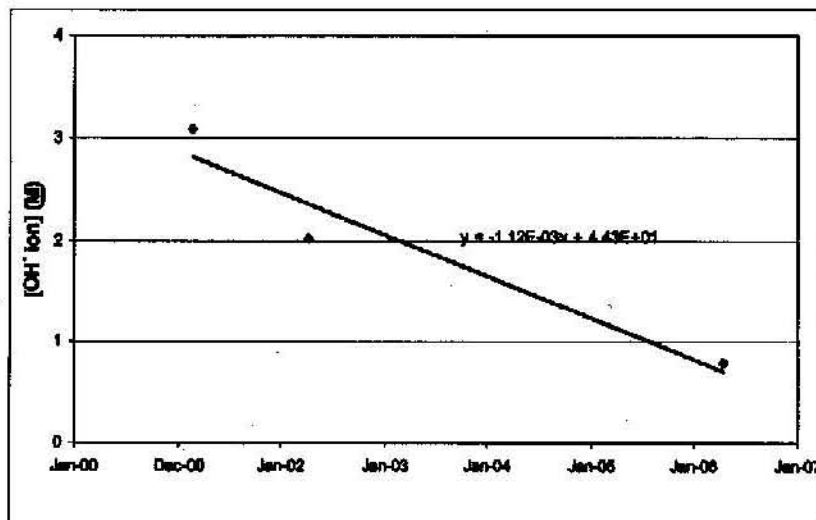
The estimated primary tank ventilation flow rate for Tank 241-AW-105 is 139 cfm, (Table 4-7).

3.2.7 Tank 241-AY-101

Figure 3-19 and Table 3-9 shows the Tank 241-AY-101 supernatant OH^- ion concentrations for a five year period from February 2001 to April 2006 (TWINS 2007). The first two points are averaged data; the third point is the OH^- ion concentration from the April 2006 sample event 12 in. above the sludge, RPP-PLAN-28778, 2006, *Corrosion Mitigation and Compatibility 2006 Grab Sampling and Analysis Plan*. The waste volume during the evaluation period (TWINS 2007), which varies from evaporation and periodic water additions, averages approximately 182 kgal. This tank contains 96 kgal of sludge, HNF-EP-0182, Rev. 220. The average supernatant volume by difference is approximately 86 kgal.

The average OH^- ion concentration for the evaluation period is 1.9 M. A linear regression of the OH^- ion concentration data provides an estimate of the OH^- ion depletion rate for the evaluation period. The OH^- ion depletion rate is approximately 0.41 M/yr. The maximum rate based upon the ventilation flow rate, with 100% CO_2 absorption, is 0.5 M/yr.

Figure 3-19 Tank 241-AY-101 Hydroxide Ion Concentration Data.

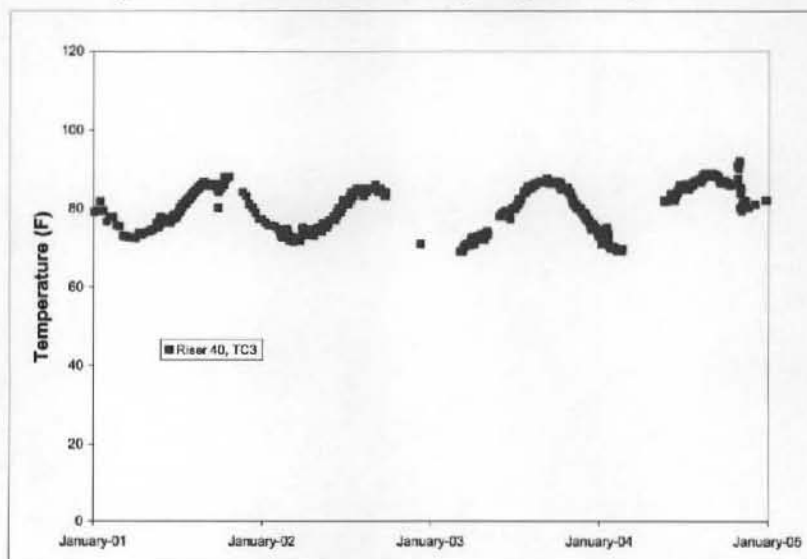


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Table 3-9 Tank 241-AY-101 Measured Hydroxide Concentrations.

Sample Event Begin Date	Reported Value (µg/mL)	OH Concentrations (M)	Sampling Event Name	Segment Name	Reference Documents
2/22/2001	54100	3.18	1AY-01-01A	NA	FH-0103352
2/22/2001	46700	2.75	1AY-01-01A	NA	FH-0103352
2/22/2001	49400	2.91	1AY-01-02A	NA	FH-0103352
2/22/2001	52600	3.09	1AY-01-02A	NA	FH-0103352
2/22/2001	52000	3.06	1AY-01-04	NA	FH-0103352
2/22/2001	54200	3.19	1AY-01-04	NA	FH-0103352
2/22/2001	57300	3.37	1AY-01-05	NA	FH-0103352
2/22/2001	53500	3.15	1AY-01-05	NA	FH-0103352
4/10/2002	33800	1.99	Core 302	1	FH-0202531
4/10/2002	34700	2.04	Core 302	1	FH-0202531
4/17/2006	13300	0.78	1AY-06-03	NA	RPP-RPT-29973

Figure 3-20 Tank 241-AY-101 Vapor Space Temperature.

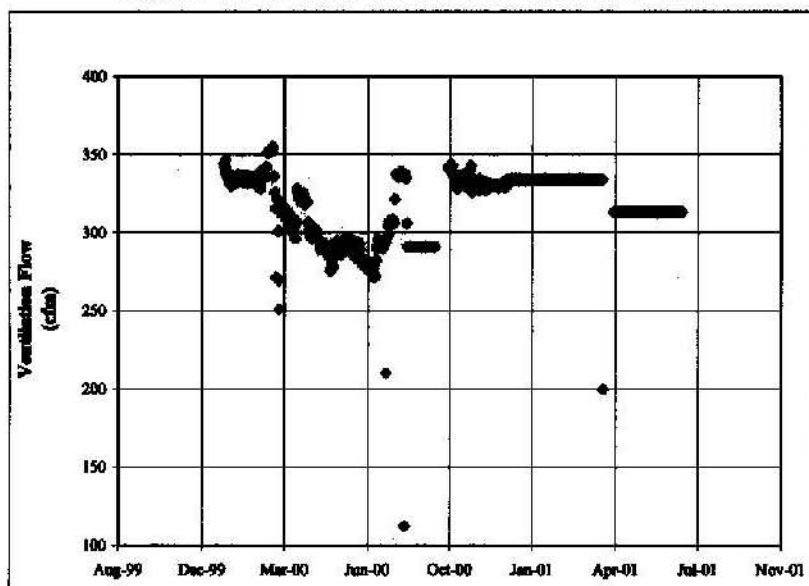


The Tank 241-AY-101 vapor space temperatures are shown in Figure 3-20 (TWINS 2007). Measured supernatant temperatures are not available. The average vapor space/supernatant temperature difference was obtained from thermal analyses of Tank 241-AY-101, RPP-12387, *Caustic Dynamic Mixing Analyses for Tanks 241-AY-101, 241-AY-102, 241-AZ-102, 241-AN-102 and 241-AN-107*. The average temperature difference used for the evaluation is 9 °F.

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The measured primary tank ventilation flow rate for Tank 241-AY-101 in 2000 and 2001 is shown in Figure 3-21. The flow rates range from about 275 cfm to 350 cfm. A flow rate of 340 cfm is assumed for the evaluation.

Figure 3-21 Tank 241-AY-101 Ventilation Flow Rate.

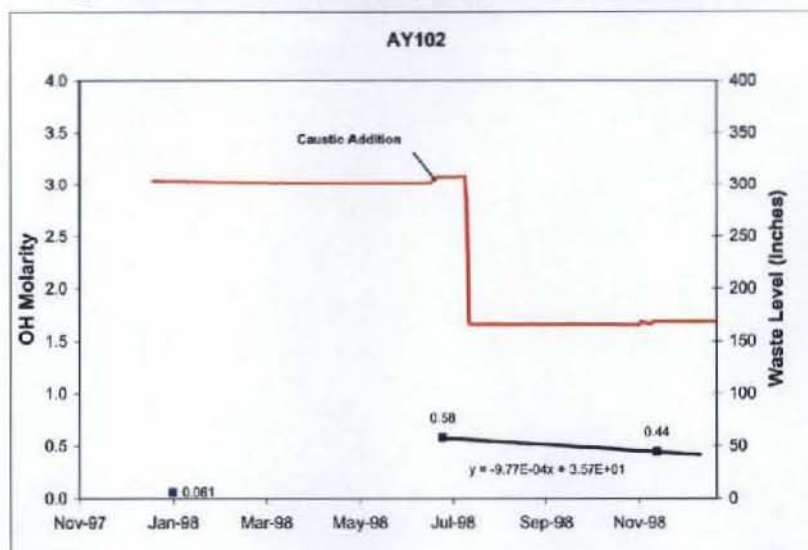


3.2.8 Tank 241-AY-102 Before Tank 241-C-106 Waste Transfer

The OH⁻ ion depletion for Tank 241-AY-102 is evaluated for a four-month period between July 1998 and November 1998. A caustic addition was made in early July 1998 in preparation for startup of Tank 241-C-106 retrieval. The tank waste volume and measured supernatant OH⁻ ion concentrations are shown in Figure 3-22 (TWINS 2007). The measured OH⁻ ion concentration data are summarized in Table 3-10. The tank volume after the caustic addition was initially at approximately 850 kgal but was reduced to approximately 457 kgal early in the period to make room for the Tank 241-C-106 waste. This tank contained about 8 in of waste (22 kgal) at this time, HNF-EP-0182, Rev 124, *Waste Tank Summary Report for Month Ending July 31, 1998*. The supernatant volume by difference is approximately 435 kgal.

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Figure 3-22 Tank 241-AY-102 Hydroxide Ion Concentration Data.



The average OH^- ion concentration for the evaluation period, July 1998 is 0.51 M. A linear regression of the OH^- ion concentration data provides an estimate of the OH^- ion depletion rate for the evaluation period. The OH^- ion depletion rate is over 0.3 M/yr. The maximum rate based upon the ventilation flow rate, with 100% CO_2 absorption, is 0.12 M/yr. The depletion rate based on the data is more uncertain because of the short evaluation period. The maximum OH^- ion depletion rate for the assumed ventilation flow rate will be used for the evaluation.

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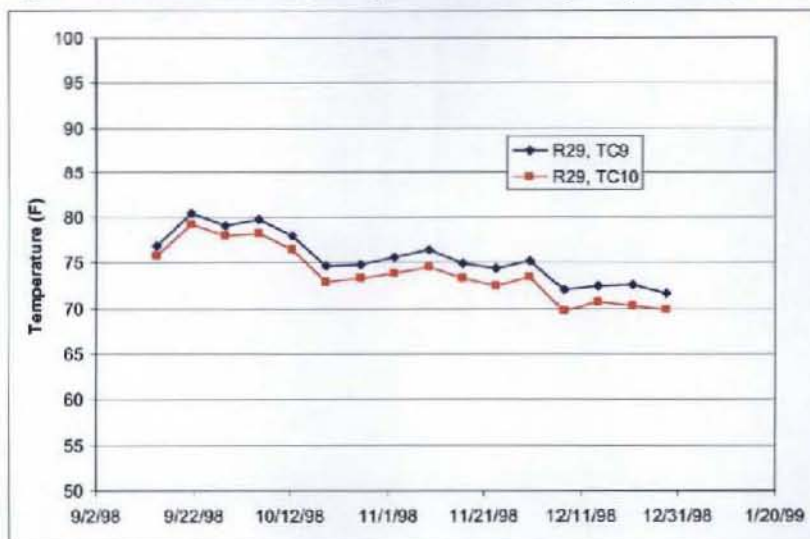
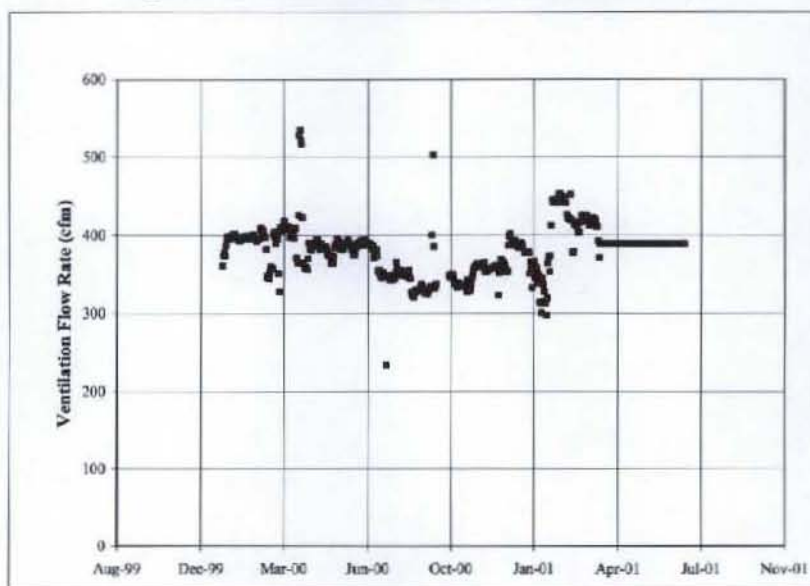
Table 3-10 Tank 241-AY-102 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Event Begin Date	Measured Value (µg/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-AY-102	Grab Sample	1/14/98	1260	0.074	0.074	HNF-SD-WM-DP-299, Rev. 0	2AY-97-2
241-AY-102	Grab Sample	1/14/98	1250	0.074		HNF-SD-WM-DP-299, Rev. 0	2AY-97-2
241-AY-102	Grab Sample	1/15/98	1270	0.075		HNF-SD-WM-DP-299, Rev. 0	2AY-97-3
241-AY-102	Grab Sample	1/15/98	1260	0.074		HNF-SD-WM-DP-299, Rev. 0	2AY-97-4
241-AY-102	Grab Sample	1/15/98	1250	0.074		HNF-SD-WM-DP-299, Rev. 0	2AY-97-1
241-AY-102	Grab Sample	1/15/98	1270	0.075		HNF-SD-WM-DP-299, Rev. 0	2AY-97-3
241-AY-102	Grab Sample	1/15/98	1260	0.074		HNF-SD-WM-DP-299, Rev. 0	2AY-97-4
241-AY-102	Grab Sample	1/15/98	1260	0.074		HNF-SD-WM-DP-299, Rev. 0	2AY-97-1
241-AY-102	Grab Sample	7/7/98	9800	0.576	0.576	HNF-1682 Rev. 0	2AY-98-4
241-AY-102	Grab Sample	7/7/98	9440	0.555		HNF-1682 Rev. 0	2AY-98-2
241-AY-102	Grab Sample	7/7/98	9800	0.576		HNF-1682 Rev. 0	2AY-98-1
241-AY-102	Grab Sample	7/7/98	9800	0.576		HNF-1682 Rev. 0	2AY-98-3
241-AY-102	Grab Sample	7/7/98	9960	0.586		HNF-1682 Rev. 0	2AY-98-4
241-AY-102	Grab Sample	7/7/98	9800	0.576		HNF-1682 Rev. 0	2AY-98-2
241-AY-102	Grab Sample	7/7/98	9930	0.584		HNF-1682 Rev. 0	2AY-98-1
241-AY-102	Grab Sample	7/7/98	9800	0.576		HNF-1682 Rev. 0	2AY-98-3
241-AY-102	Grab Sample	11/22/98	6540	0.385	0.413	HNF-1682 Rev. 0	2AY-98-6
241-AY-102	Grab Sample	11/22/98	7360	0.433		HNF-1682 Rev. 0	2AY-98-5
241-AY-102	Grab Sample	11/22/98	6310	0.371		HNF-1682 Rev. 0	2AY-98-6
241-AY-102	Grab Sample	11/22/98	7430	0.437		HNF-1682 Rev. 0	2AY-98-5
241-AY-102	Grab Sample	12/20/98	6940	0.408		HNF-1682 Rev. 0	2AY-98-8
241-AY-102	Grab Sample	12/20/98	7270	0.428		HNF-1682 Rev. 0	2AY-98-7
241-AY-102	Grab Sample	12/20/98	6840	0.402		HNF-1682 Rev. 0	2AY-98-8
241-AY-102	Grab Sample	12/20/98	7500	0.441		HNF-1682 Rev. 0	2AY-98-7

The Tank 241-AY-102 vapor space and supernatant temperatures are shown in Figure 3-23 (TWINS 2007). The average temperature difference is approximately 4 °F.

The measured primary tank ventilation flow rates for Tank 241-AY-102 in 2000 and 2001 are shown in Figure 3-24. The flow rates range from about 300 cfm to 500 cfm. The actual flow rate during the evaluation period is not known. A flow rate of 425 cfm is used for the evaluation. This appears to be consistent with the high OH⁻ ion depletion rate.

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Figure 3-23 Tank 241-AY-102 Supernatant and Vapor Space Temperature.**Figure 3-24 Tank 241-AY-102 Ventilation Flow Rate.****3.2.9 Tank 241-AY-102**

The OH^- ion depletion for Tank 241-AY-102 is evaluated for a twenty-month period from March 2001 to November 2002. The tank waste volume and measured supernatant OH^- ion concentrations are shown in Figure 3-25 (TWINS 2005). The measured OH^- ion concentration data are summarized in Table 3-11. The average tank volume during the evaluation period is approximately 639 kgal. This tank contains 151 kgal of sludge solid waste, HNF-EP-0182, Rev. 220. Therefore, the average supernatant volume during the evaluation period is 488 kgal.

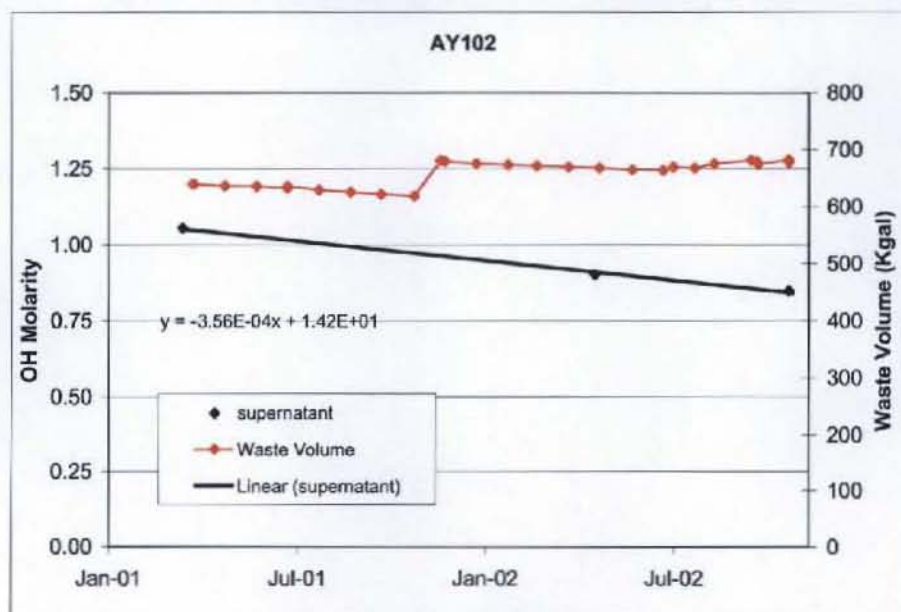
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The OH⁻ ion concentrations shown in Figure 3-25 represent the mid-points for the data presented in Table 3-11. The average value for the evaluation period is approximately 0.95 M. A linear regression of the OH⁻ ion concentration data provides an estimate of the OH⁻ ion depletion rate for the evaluation period. The OH⁻ ion depletion rate is approximately 0.13 M/yr. The maximum rate based upon the ventilation flow rate, with 100% CO₂ absorption, is 0.11 M/yr. The data exceeds the maximum rate. Because of the uncertainty in the OH⁻ ion concentration data and the primary tank ventilation flow rate, the maximum value for the assumed ventilation flow rate will be used for the benchmark analyses.

Tank 241-AY-102 vapor space and supernatant temperatures are shown in Figure 3-26 (TWINS 2005). The average temperature difference between the vapor space and supernatant shown in Figure 3-26 is only 3.1 °F. The estimated heat load for this tank is 129,000 BTU/hr, RPP-12387. The heat load reported in RPP-5926, 127,400 BTU/hr, supports the RPP-12387 estimate.

The estimated primary tank ventilation flow rate for Tank 241-AY-102 is 425 cfm, based on flow rate measurements between November 1999 and July 2001, Figure 3-24.

Figure 3-25 Tank 241-AY-102 Hydroxide Ion Concentration Data.



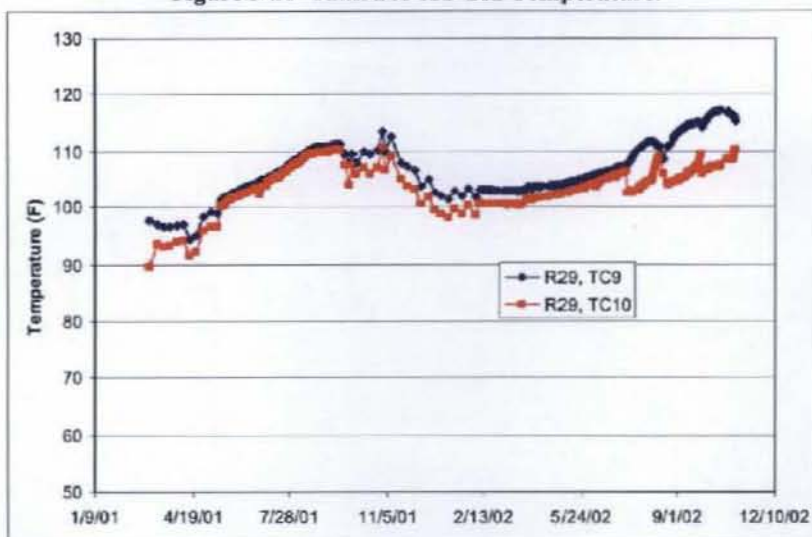
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Table 3-11 Tank 241-AY-102 Measured Hydroxide Concentrations.

Sample Event Begin Date	OH ⁻ Molarity	Sampling Event Type	Segment	Phase	Source Document
March 2001	1.1	Post Caustic Addition Grab Sample, 2AY-01-05	n/a	Supernatant	FH-0103293, Reissue 2
March 2001	1.16	Post Caustic Addition Grab Sample, 2AY-01-05	n/a	Supernatant	FH-0103293, Reissue 2
March 2001	1.14	Post Caustic Addition Grab Sample, 2AY-01-06	n/a	Supernatant	FH-0103293, Reissue 2
March 2001	1.08	Post Caustic Addition Grab Sample, 2AY-01-06	n/a	Supernatant	FH-0103293, Reissue 2
March 2001	1.11	Post Caustic Addition Grab Sample, 2AY-01-07	n/a	Supernatant	FH-0103293, Reissue 2
March 2001	1.10	Post Caustic Addition Grab Sample, 2AY-01-07	n/a	Supernatant	FH-0103293, Reissue 2
March 2001	1.19	Post Caustic Addition Grab Sample Composite (2AY-01-05, 06, 07)	n/a	Supernatant	FH-0103293, Reissue 2
March 2001	1.18	Post Caustic Addition Grab Sample Composite (2AY-01-05, 06, 07)	n/a	Supernatant	FH-0103293, Reissue 2
March 2001	1.03	Post Caustic Addition Core 290	1	Supernatant	FH-0103293, Reissue 2
March 2001	1.11	Post Caustic Addition Core 290	1	Supernatant	FH-0103293, Reissue 2
March 2001	1.05	Post Caustic Addition Core 290	5	Supernatant	FH-0103293, Reissue 2
March 2001	1.07	Post Caustic Addition Core 290	5	Supernatant	FH-0103293, Reissue 2
March 2001	0.92	Post Caustic Addition Core 290	9	Supernatant	FH-0103293, Reissue 2
March 2001	0.98	Post Caustic Addition Core 290	9	Supernatant	FH-0103293, Reissue 2
March 2001	1.09	Post Caustic Addition Core 290 Composite	1,5,9	Supernatant	FH-0103293, Reissue 2
March 2001	1.03	Post Caustic Addition Core 290 Composite	1,5,9	Supernatant	FH-0103293, Reissue 2
April 2002	0.84	Core 300	1	Supernatant	FH-0202868, Reissue 1
April 2002	0.86	Core 300	1	Supernatant	FH-0202868, Reissue 1
November 2002	0.74	Grab Sample	n/a	Supernatant	FH-0205402
November 2002	0.75	Grab Sample	n/a	Supernatant	FH-0205402
November 2002	0.69	Grab Sample	n/a	Supernatant	FH-0205402
November 2002	0.88	Grab Sample	n/a	Supernatant	FH-0205402
November 2002	0.69	Grab Sample	n/a	Supernatant	FH-0205402
November 2002	0.71	Grab Sample	n/a	Supernatant	FH-0205402
November 2002	0.71	Grab Sample	n/a	Supernatant	FH-0205402
November 2002	0.76	Grab Sample	n/a	Supernatant	FH-0205402

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Figure 3-26 Tank 241-AY-102 Temperature.



3.2.10 Tank 241-AZ-101

The OH⁻ ion depletion for Tank 241-AZ-101 is evaluated for a period of nearly thirteen years, October 1987 to May 2000. The tank waste volume and measured supernatant OH⁻ ion concentrations are shown in Figure 3-27 (TWINS 2005). The measured OH⁻ ion concentration data are contained in Table 3-12. The average tank volume during the evaluation period is 916 kgal. This tank contains 52 kgal of sludge solid waste, HNF-EP-0182, Rev 220. Thus, the average supernatant volume during the evaluation period is 864 kgal.

The OH⁻ ion concentrations shown in Figure 3-27 represent the mid-point for the sample data from Table 3-12. The average value for the evaluation period is 0.81 M. The May 2000 data was adjusted to account for the decrease in supernatant volume through evaporation. The adjusted value is shown in Figure 3-27. A linear regression of the OH⁻ ion concentration data provides an estimate of the OH⁻ ion depletion rate for the evaluation period. The OH⁻ ion depletion rate is approximately 0.016 M/yr. The maximum rate based upon the ventilation flow rate, with 100% CO₂ absorption, is 0.022 M/yr.

Tank 241-AZ-101 supernatant temperatures (R54, TC3) are shown in Figure 3-28 (TWINS 2007). Also shown is an embedded thermocouple in the dome region. The vapor space-supernatant temperature difference can not be quantified from these data. The average value for all the other Hanford Site tanks which are evaluated in Section 3.0 is used (2.0 °F).

The estimated primary tank ventilation flow rate for Tank 241-AZ-101 is 149 cfm, based on measured flow rates between November 1999 and July 2001.

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Figure 3-27 Tank 241-AZ-101 Hydroxide Ion Concentration Data.

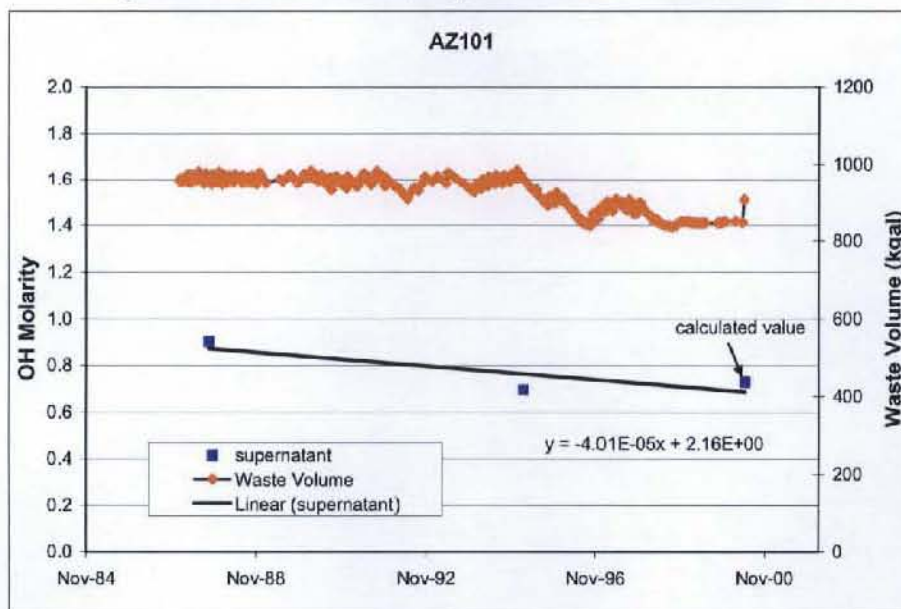


Table 3-12 Tank 241-AZ-101 Measured Hydroxide Concentrations.

Sample Event Begin Date	OH Molarity	Sampling Event Type	Segment	Phase	Source Document
October 1987	0.90	Grab Sample	n/a	Supernatant	12221-PCL88-091
March 1995	0.653	Grab Sample	n/a	Supernatant	75970-95-037
March 1995	0.659	Grab Sample	n/a	Supernatant	75970-95-037
March 1995	0.659	Grab Sample	n/a	Supernatant	75970-95-037
March 1995	0.665	Grab Sample	n/a	Supernatant	75970-95-037
March 1995	0.665	Grab Sample	n/a	Supernatant	75970-95-037
March 1995	0.735	Grab Sample	n/a	Supernatant	75970-95-037
May 2000	0.829	Grab Sample ⁴	n/a	Supernatant	FH-0201779
May 2000	0.835	Grab Sample	n/a	Supernatant	FH-0201779

⁴ Grab sample taken during mixer pump test. Measurement includes interstitial fluid which is less than 6% of the supernatant volume.

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Figure 3-28 Tank 241-AZ-101 Temperature.

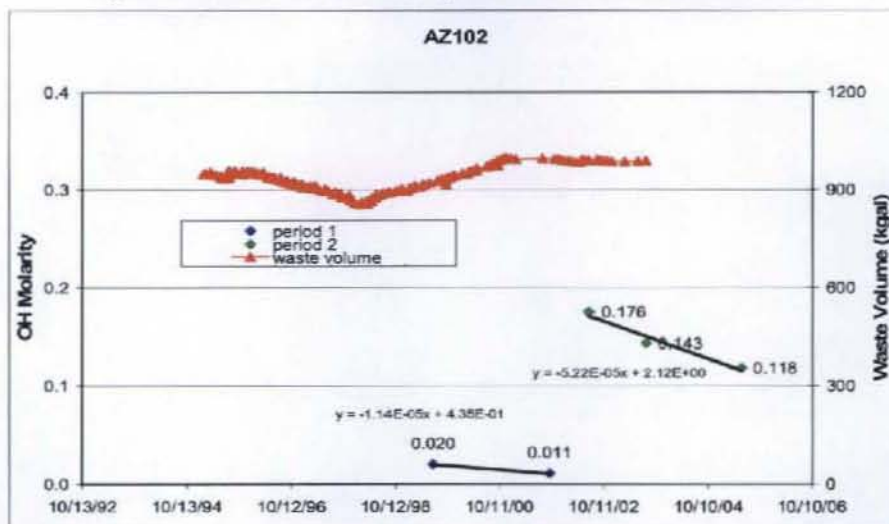


3.2.11 Tank 241-AZ-102

The OH⁻ ion depletion for Tank 241-AZ-102 spans two periods shown in Figure 3-29. The first is a period of approximately seven years, February 1995 to October 2001. The second, after the May 2002 caustic addition to Tank 241-AZ-102, is a period of approximately three years, July 2002 to June 2005. The tank waste volume and measured supernatant OH⁻ ion concentrations are shown in Figure 3-29 (TWINS 2005). The measured OH⁻ ion concentration data are contained in Tables 3-13 and 3-14. The average tank volume during the first evaluation period is 962 kgal. This tank contains 105 kgal of sludge solid waste, HNF-EP-0182, Rev 163, *Waste Tank Summary Report for Month Ending October 31, 2001*. Therefore, the average supernatant volume during the first evaluation period is 857 kgal. The average tank volume during the second evaluation period is 996 kgal. The average supernatant volume during the second evaluation period is 891 kgal.

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Figure 3-29 Tank 241-AZ-102 Hydroxide Ion Concentration Data.



The OH^- ion concentrations shown in Figure 3-29 represent the mid-point for the sample data from Tables 3-13 and 3-14. The average value for the first evaluation period is 0.016 M. A linear regression of the OH^- ion concentration data provides an estimate of the OH^- ion depletion rate for the first evaluation period. The OH^- ion depletion rate is approximately 0.004 M/yr. The maximum rate based upon the ventilation flow rate, with 100% CO_2 absorption, is 0.015 M/yr.

The average OH^- ion concentration for the second evaluation period is 0.15 M. A linear regression of the OH^- ion concentration data provides an estimate of the OH^- ion depletion rate for the second evaluation period. The OH^- ion depletion rate is approximately 0.019 M/yr. The maximum rate based upon the ventilation flow rate, with 100% CO_2 absorption, is 0.014 M/yr. The measured OH^- ion depletion rate is slightly greater than the maximum value. Because of uncertainty in the OH^- ion concentration data and the primary ventilation flow data, the maximum value based on 100% CO_2 absorption from the ventilation air will be used for the evaluation.

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Table 3-13 Tank 241-AZ-102 Measured Hydroxide Concentrations.

Sample Event Begin Date	OH ⁻ Molarity ⁵	Sampling Event Type	Segment	Phase	Source Document
February 1995	0.117	Grab Sample	n/a	Supernatant	75970-95-039, Revision 1
February 1995	0.109	Grab Sample	n/a	Supernatant	75970-95-039, Revision 1
February 1995	0.108	Grab Sample	n/a	Supernatant	75970-95-039, Revision 1
February 1995	0.108	Grab Sample	n/a	Supernatant	75970-95-039, Revision 1
June 1999	0.026	Core 261	1	Supernatant	HNF-1697, Rev. 0A
June 1999	0.027	Core 261	2	Supernatant	HNF-1697, Rev. 0A
June 1999	0.028	Core 261	3	Supernatant	HNF-1697, Rev. 0A
June 1999	0.029	Core 261	4	Supernatant	HNF-1697, Rev. 0A
June 1999	0.027	Core 261	5	Supernatant	HNF-1697, Rev. 0A
June 1999	0.026	Core 261	6	Supernatant	HNF-1697, Rev. 0A
June 1999	0.030	Core 261	7	Supernatant	HNF-1697, Rev. 0A
June 1999	0.026	Core 261	8	Supernatant	HNF-1697, Rev. 0A
June 1999	0.026	Core 261	9	Supernatant	HNF-1697, Rev. 0A
June 1999	0.023	Core 261	10	Supernatant	HNF-1697, Rev. 0A
June 1999	0.025	Core 261	11	Supernatant	HNF-1697, Rev. 0A
June 1999	0.029	Core 261	12	Supernatant	HNF-1697, Rev. 0A
June 1999	0.024	Core 261	13	Supernatant	HNF-1697, Rev. 0A
June 1999	0.021	Core 261	14	Supernatant	HNF-1697, Rev. 0A
June 1999	0.027	Core 261	15	Supernatant	HNF-1697, Rev. 0A
June 1999	0.025	Core 261	16	Supernatant	HNF-1697, Rev. 0A
July 1999	0.021	Core 262	1	Supernatant	HNF-1697, Rev. 0A
July 1999	0.026	Core 262	2	Supernatant	HNF-1697, Rev. 0A
July 1999	0.018	Core 262	3	Supernatant	HNF-1697, Rev. 0A
July 1999	0.021	Core 262	4	Supernatant	HNF-1697, Rev. 0A
July 1999	0.006	Core 262	5	Supernatant	HNF-1697, Rev. 0A
July 1999	0.010	Core 262	6	Supernatant	HNF-1697, Rev. 0A
July 1999	0.004	Core 262	7	Supernatant	HNF-1697, Rev. 0A
July 1999	0.013	Core 262	8	Supernatant	HNF-1697, Rev. 0A
July 1999	0.026	Core 262	9	Supernatant	HNF-1697, Rev. 0A
July 1999	0.011	Core 262	10	Supernatant	HNF-1697, Rev. 0A

⁵ July 1999 OH⁻ ion concentrations calculated based on pH measurements.

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Table 3-14 Tank 241-AZ-102 Measured Hydroxide Concentrations, continued.

Sample Event Begin Date	OH Molarity ⁶	Sampling Event Type	Segment	Phase	Source Document
July 1999	0.008	Core 262	11	Supernatant	HNF-1697, Rev. 0A
July 1999	0.029	Core 262	12	Supernatant	HNF-1697, Rev. 0A
July 1999	0.024	Core 262	13	Supernatant	HNF-1697, Rev. 0A
July 1999	0.035	Core 262	14	Supernatant	HNF-1697, Rev. 0A
July 1999	0.037	Core 262	14	Supernatant	HNF-1697, Rev. 0A
July 1999	0.039	Core 262	15	Supernatant	HNF-1697, Rev. 0A
July 1999	0.040	Core 262	15	Supernatant	HNF-1697, Rev. 0A
July 1999	0.001	Core 262	16	Supernatant	HNF-1697, Rev. 0A
July 1999	0.001	Core 262	16	Supernatant	HNF-1697, Rev. 0A
July 1999	0.024	Core 262	17	Supernatant	HNF-1697, Rev. 0A
July 1999	0.025	Core 262	17	Supernatant	HNF-1697, Rev. 0A
July 1999	0.026	Core 262	17R	Supernatant	HNF-1697, Rev. 0A
July 1999	0.026	Core 262	17R	Supernatant	HNF-1697, Rev. 0A
September 1999	0.023	Core 268	16	Supernatant	HNF-1697, Rev. 0A
September 1999	0.023	Core 268	16	Supernatant	HNF-1697, Rev. 0A
September 1999	0.025	Core 268	17R	Supernatant	HNF-1697, Rev. 0A
September 1999	0.025	Core 268	17R	Supernatant	HNF-1697, Rev. 0A
October 2001	0.010	Grab Sample, 2AZ-01-02	n/a	Supernatant	FH-0106497, Reissue
October 2001	0.013	Grab Sample, 2AZ-01-02	n/a	Supernatant	FH-0106497, Reissue
October 2001	0.007	Grab Sample, 2AZ-01-02, Caustic Demand Analytical Result	n/a	Supernatant	FH-0107012
July 2002	0.186	Core 303	1	Supernatant	FH-0204059, Reissue 2
July 2002	0.169	Core 303	1	Supernatant	FH-0204059, Reissue 2
July 2002	0.165	Core 303	9	Supernatant	FH-0204059, Reissue 2
August 2003	0.142	Core 310	1R1	Supernatant	7S120-RWS-03-003, Reissue 3
August 2003	0.144	Core 310	1R1	Supernatant	7S120-RWS-03-003, Reissue 3
June 2005	0.113	Core 316	1	Supernatant	05-ATL-064, Reissue 1
June 2005	0.123	Core 316	1	Supernatant	05-ATL-064, Reissue 1

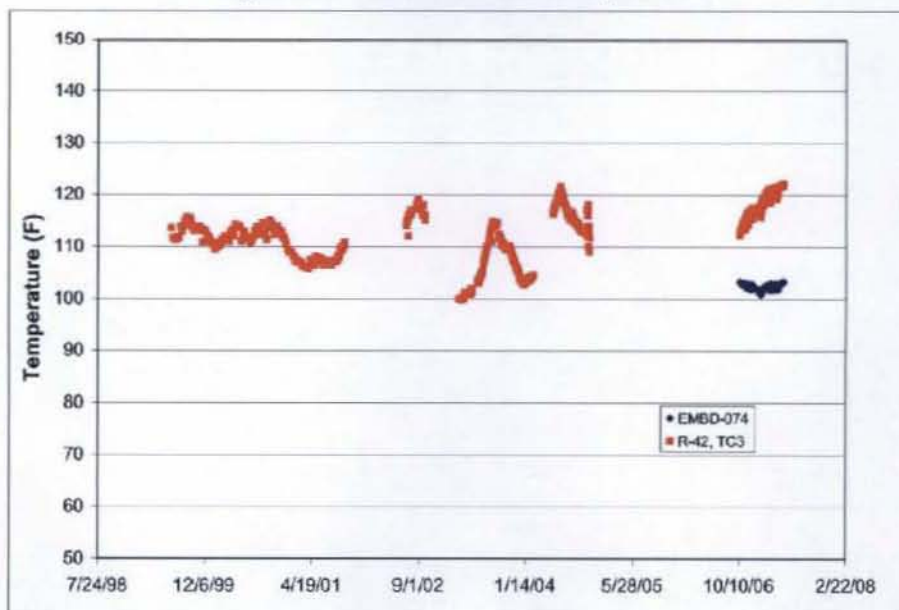
Tank 241-AZ-102 supernatant temperatures (R42, TC3) are shown in Figure 3-30 (TWINS 2007). Also shown is an embedded thermocouple in the dome region. The vapor space-supernatant temperature difference can not be quantified from these data. The average value for all the other Hanford tanks which are evaluated in Section 3.0 is used (2.0 °F).

⁶ July 1999, September 1999 and October 2001 OH⁻ ion concentrations based on pH measurements.

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The estimated primary tank ventilation flow rate for Tank 241-AZ-102 is 102 cfm, based on the measured flow rates between November 1999 and July 2001.

Figure 3-30 Tank 241-AZ-102 Temperature.



3.3 HANFORD SITE VAPOR SPACE CARBON DIOXIDE DATA

Vapor space sample data were obtained from selected Hanford Site waste tanks in support of the Flammable Gas Program. These data included the CO₂ concentrations. The CO₂ data are available in TWINS for the following double-shell tanks:

- **241-AN Farm**
 - Tank 241-AN-101
 - Tank 241-AN-103
 - Tank 241-AN-104
 - Tank 241-AN-105
 - Tank 241-AN-107
 - 241-AN Farm Ventilation
- **241-AP Farm**
 - Tank 241-AP-101
 - Tank 241-AP-102
 - Tank 241-AP-104
 - Tank 241-AP-106
 - 241-AP Farm Ventilation

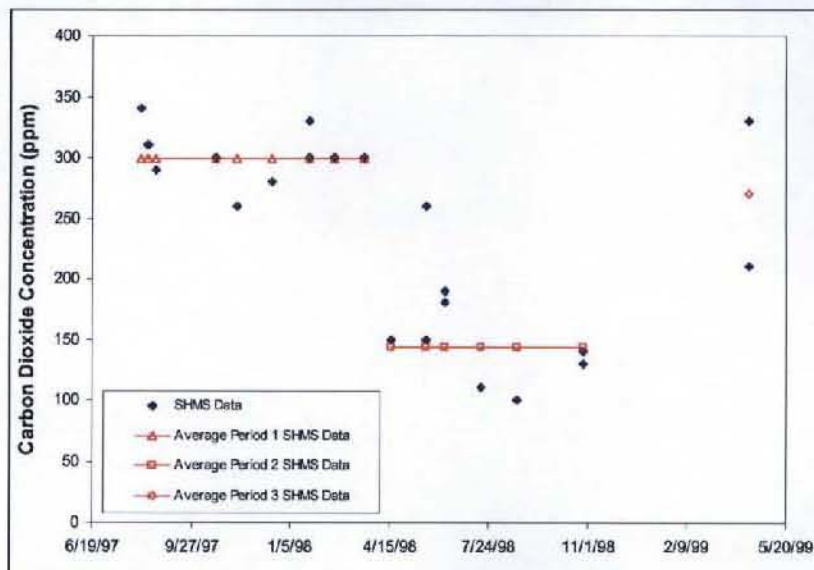
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- **241-AW Farm**
Tank 241-AW-101
241-AW Farm Ventilation
- **241-SY Farm**
Tank 241-SY-101
Tank 241-SY-102
Tank 241-SY-103
241-SY Farm Ventilation
- **Aging Waste Tanks**
Tank 241-AY-102
Tank 241-AZ-101
Tank 241-AZ-102
AWF Ventilation

Data are available for these DSTs and tank farm ventilation systems from April 1993 through July 2001. Measurements were made in the head space of individual tanks using the Standard Hydrogen Monitoring System (SHMS) and in the outlet ventilation air stream for each of the DST farms. These data are useful for benchmarking the mechanistic hydroxide depletion model.

An example of the vapor space CO₂ data is shown in Figure 3-31. The figure shows the data for Tank 241-AY-102. There is typically considerable scatter in the CO₂ data. The values are averaged over representative periods to provide data points useful for benchmarking the mechanistic hydroxide depletion model.

Figure 3-31 Tank 241-AY-102 Measured Vapor Space CO₂ Concentrations.



4.0 BENCHMARK OF THE MECHANISTIC DEPLETION MODEL

The mechanistic hydroxide depletion model and the Hobbs depletion model presented in Section 2.0 have been benchmarked using the SRS and Hanford Site data presented in Section 3.0. The models have been used to predict the rate of OH^- ion depletion through the absorption of CO_2 . The predicted CO_2 absorption fraction is compared to the measured CO_2 absorption fraction for the SRS data. The predicted OH^- ion molarity depletion rate is compared with the molarity depletion rate derived from OH^- ion concentrations for the Hanford Site data. Results of the benchmark analyses comparison are presented in the following sections.

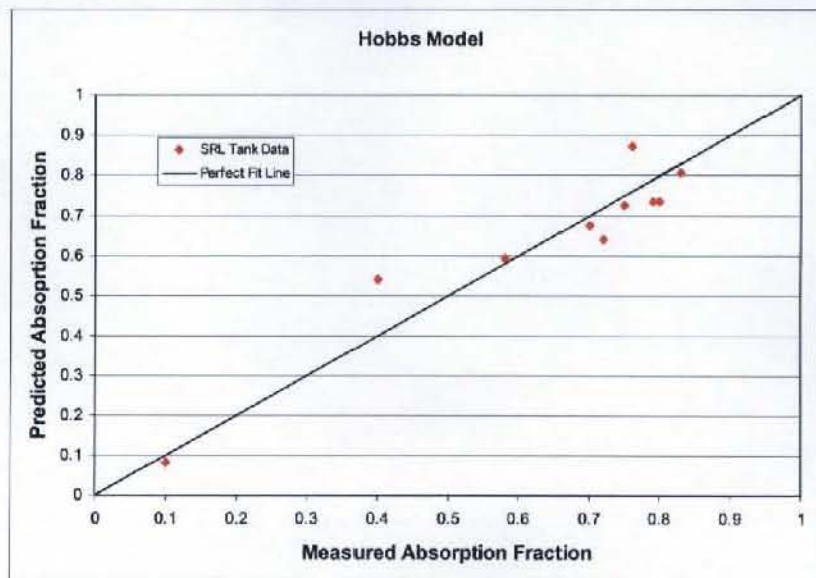
4.1 SAVANNAH RIVER SITE DATA

The SRS data related to the OH^- ion depletion from H-Area waste tanks is used to benchmark the mechanistic and Hobbs depletion models. Data for the H-Area waste tanks is included in Table 3-1.

4.1.1 Hobbs Depletion Model Benchmark Using the SRS Data

The Hobbs depletion model presented in Section 2.2 is an empirically based model. The CO_2 absorption fraction is determined from the SRS data presented in Table 3-1. The CO_2 absorption fraction is only a function of the supernatant OH^- ion concentration, as shown in Equation 2-5.

Figure 4-1 Hobbs Model Prediction of Carbon Dioxide Absorption Fraction for SRS Data.



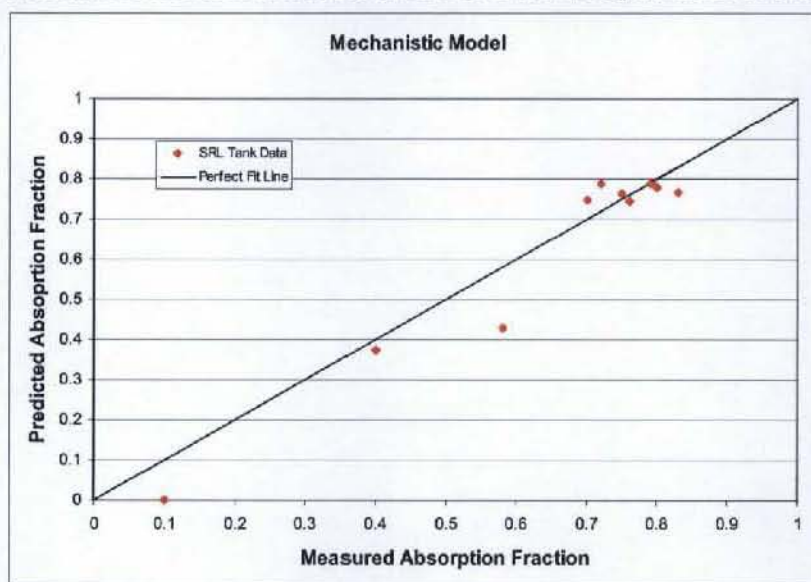
The Hobbs depletion model is used to predict the OH^- ion depletion for the SRS H-Area tanks. The predicted CO_2 absorption fraction, Equation 2-5, is compared to the measured CO_2 absorption fraction in Figure 4-1. The measured CO_2 absorption fractions range from about 10% to 83%, Table 3-1. If the Hobbs model were able to predict the CO_2 absorption fraction

perfectly, all the points would lie on the best fit line. There is generally good agreement with the data, as shown on Figure 4-1, since the Hobbs model is an empirical model derived from the SRS data set.

4.1.2 Mechanistic Depletion Model Benchmark Using the SRS Data

The mechanistic depletion model presented in Section 2.3 uses the Colburn analogy to determine, on a mechanistic basis, the CO_2 mass transfer rate at the supernatant surface. The CO_2 mass transfer rate, related to the CO_2 absorption fraction in the Hobbs model, is a function of the primary tank ventilation flow rate, the temperature difference between the vapor space and supernatant, and the supernatant OH^- ion concentration when OH^- ion concentrations are low (see Figure 2-2).

Figure 4-2 Mechanistic Model Prediction of Carbon Dioxide Absorption Fraction for SRS Data.



The mechanistic depletion model is used to predict OH^- ion depletion for the SRS H-Area tanks. The predicted CO_2 absorption fraction is compared to the measured CO_2 absorption fraction in Figure 4-2. The mechanistic prediction agrees well with the data. The mechanistic depletion model under-predicts the absorption fraction for the lowest value. The OH^- ion concentration for this data point is 0.0001 M , two orders of magnitude less than the lowest AC 5.16 OH^- ion concentration limit. There is less scatter in the predictions for higher CO_2 absorption values, when compared to the Hobbs model plot in Figure 4-1.

The benchmark analyses using the SRS data indicates the mechanistic depletion model is as accurate as the Hobbs depletion model. Additionally, mechanistic prediction of CO_2 mass transfer as a function of primary tank ventilation flow rate, vapor space/supernatant temperature difference and OH^- ion concentration provides a better understanding of the OH^- ion depletion process.

4.2 HANFORD SITE SUPERNATANT HYDROXIDE DATA

The Hanford Site DST data related to OH⁻ ion depletion, Table 3-2, are used to benchmark the Hobbs depletion prediction and the mechanistic depletion model.

4.2.1 Hobbs Depletion Model Benchmark Using the Hanford Site Data

Results of the Hobbs hydroxide depletion model benchmark using the Hanford Site DST data are shown in Figure 4-3. The molarity depletion rate is derived from the CO₂ absorption fraction of the Hobbs model, from Equation 2-5, using Equation 4-1 and Table 3-2 data.

$$(4-1) \quad OH_{Hobbs_Depletion_rate} = \frac{2 \cdot [CO_2]_{air_{amb}} \cdot Q_{vent} \cdot F_{hobbs}}{V_{supernatant}}$$

Where:

$[CO_2]_{air_{amb}}$ is the concentration of CO₂ in the inlet air stream.

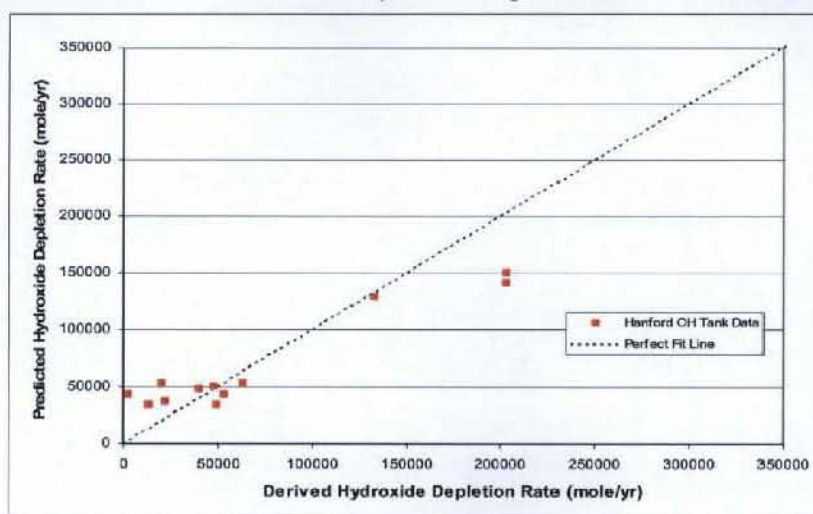
Q_{vent} is the primary tank ventilation flow rate.

$V_{supernatant}$ is the tank supernatant volume.

F_{hobbs} is the CO₂ absorption fraction predicted by the Hobbs model.

The Hobbs model OH⁻ ion depletion rates generally agree well with the data. The uncertainty in the predicted OH⁻ ion depletion rate is larger than the uncertainty in the predicted absorption fraction for the SRS data. This is primarily due to greater uncertainty in the Hanford Site OH⁻ ion data. The SRS data were derived from relatively short duration, controlled tests where the OH⁻ ion depletion rate was determined by measurement of CO₂ in the ventilation air. The OH⁻ ion depletion rate for the Hanford Site tanks was derived from OH⁻ ion concentration data, which had a considerable amount of scatter. The OH⁻ ion concentration measurements were also taken over much longer periods of the time.

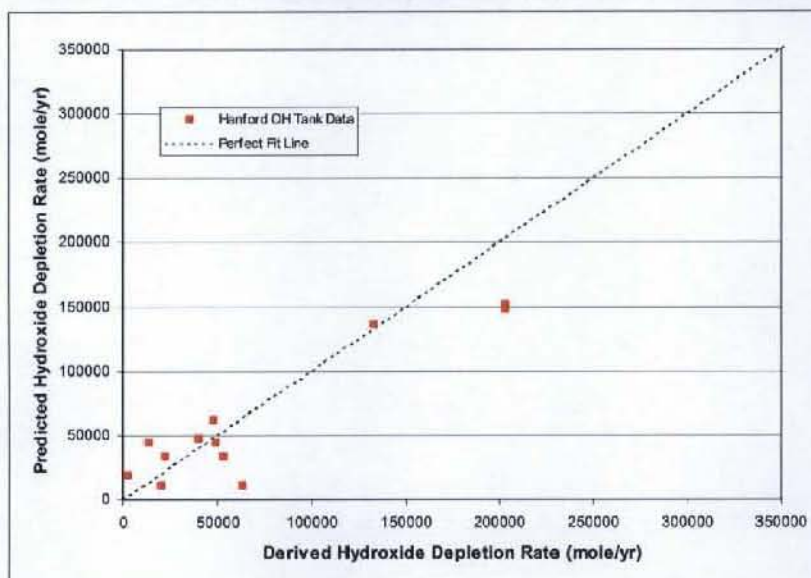
Figure 4-3 Hobbs Model Prediction of Hydroxide Depletion Rate for Hanford Site Data.



4.2.2 Mechanistic Depletion Model Benchmark Using the Hanford Site Data

The results of the mechanistic hydroxide depletion model benchmark using the Hanford Site DST data are shown in Figure 4-4.

Figure 4-4 Mechanistic Model Predictions of Hydroxide Depletion Rates for Hanford Site Data.



The mechanistically predicted OH^- ion depletion rates are in reasonable agreement with the measured data.

The predicted CO_2 absorption fraction and OH^- ion depletion rates (in both moles and molarity) are shown in Table 4-1 for the Hanford Site DSTs evaluated. The predicted CO_2 absorption fractions range from 90% for Tank 241-AZ-102 to as low as 18% for Tank 241-AN-104, which has a crust limiting the air-liquid interface mass transfer. The predicted OH^- ion depletion rates range from 0.004 M/yr for Tank 241-AW-105 to 0.41 M/yr for Tank 241-AY-101. The OH^- ion mole depletion rate for the ten tanks ranges from a low of 10,600 moles/yr in Tank 241-AN-104 to 151,600 moles/yr in Tank 241-AY-102.

Both the Hobbs model and the mechanistic depletion model compare reasonably well with the SRS and Hanford Site supernatant OH^- ion concentration data. However, since the mechanistic model is not an empirical equation, but is based upon physical mechanisms, it has a wider range of application. This is demonstrated with the evaluation of the Hanford Site vapor space CO_2 data in Section 4.3.

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Table 4-1 Summary of Results for Mechanistic Model for Hanford Site Data.

Tank-241	Predicted CO ₂ Absorption Fraction	CO ₂ Absorption Fraction Inferred from OH Data	Predicted OH ⁻ Depletion Rate (Moles/yr)	Predicted OH ⁻ Depletion Rate (M/yr)	Measured OH ⁻ Depletion Rate Data (M/yr)
AN-104	17%	31%	10,600	0.005	0.009
AN-105	18%	99%	11,100	0.005	0.028
AP-101	63%	99%	33,200	0.008	0.013
AP-103	63%	41%	33,200	0.031	0.020
AW-103	70%	60%	46,500	0.016	0.013
AW-105	28%	4%	18,400	0.031	0.004
AY-101	83%	82%	136,000	0.416	0.41
AY-102 (1998)	75%	99%	151,600	0.092	0.12
AY-102 (2001)	73%	99%	148,100	0.08	0.11
AZ-101	87%	67%	61,700	0.019	0.016
AZ-102 (1999)	90%	28%	44,200	0.014	0.004
AZ-102 (2002)	90%	99%	44,200	0.013	0.014

4.3 HANFORD SITE VAPOR SPACE CARBON DIOXIDE DATA

The DSTs with vapor space CO₂ data identified in Section 3.3 are used to further benchmark the mechanistic hydroxide depletion model. The mechanistic depletion model was used to predict the OH⁻ ion depletion rate for the tank conditions at the time of the vapor space measurements. Important parameters needed for the mechanistic model analyses include:

- vapor space/supernatant temperature difference
- supernatant OH⁻ ion concentration
- ventilation flow rate
- presence of surface crust.

The fraction of CO₂ absorbed from the ventilation air stream is given by Equation 4-2, which is derived by rearranging Equation 2-3.

$$(4-2) \quad F = \frac{OH_{dep}}{[CO_2]_{air_{amb}} \cdot Q_{vent}}$$

Where:

F = CO₂ absorption fraction

OH_{dep} = OH⁻ ion depletion rate [moles/unit time]

$[CO_2]_{air_{amb}}$ = CO₂ concentration in the inlet ambient air [mole/volume]

Q_{vent} = ventilation flow rate [volume/unit time]

The predicted vapor space CO₂ concentration is given by Equation 4-3.

$$(4-3) \quad [CO_2]_{air_{bulk}} = [CO_2]_{air_{amb}} \cdot (1 - F)$$

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Where:

$$[CO_2]_{air_{bulk}} = \text{CO}_2 \text{ concentration of the vapor space [mole/volume]}$$

The vapor space CO₂ data and the benchmark analyses are presented in the following sections.

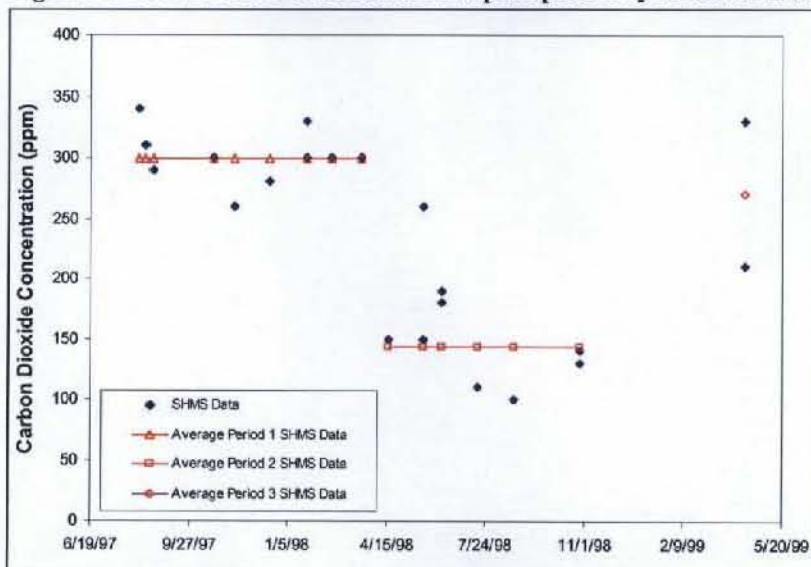
4.3.1 Tank 241-AY-102 Carbon Dioxide Data Evaluation

4.3.1.1 Tank 241-AY-102 Data

The SHMS data for the Tank 241-AY-102 vapor space are shown in Figure 4-5 (TWINS 2007). There are three time periods identified on the chart. The supernatant OH⁻ ion concentration was different for these three periods resulting in a change in the CO₂ absorption rate and the CO₂ vapor space concentration. The measured supernatant OH⁻ ion concentrations are shown in Figure 4-6 and Table 3-10 and Table 4-2 (TWINS 2007). In January 1998, the supernatant OH⁻ ion concentration was 0.074 M. The concentration increased to 0.58 M in July 1998 due to a caustic addition to the supernatant. By April 1999, the OH⁻ ion concentration has decreased to 0.082 M. The buffering of the OH⁻ ion affects the CO₂ concentration in the aqueous phase and the CO₂ absorption rate. This buffering is important at low OH⁻ ion concentrations.

The ventilation flow rate, supernatant temperature and vapor space/supernatant temperature difference used for the mechanistic model calculation are presented in Section 3.2.8 and 3.2.9. The results of the mechanistic model analyses are shown in Figure 4-7 and discussed in the following sections.

Figure 4-5 Tank 241-AY-102 Measured Vapor Space CO₂ Concentrations.



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Figure 4-6 Tank 241-AY-102 Supernatant Hydroxide Concentrations.

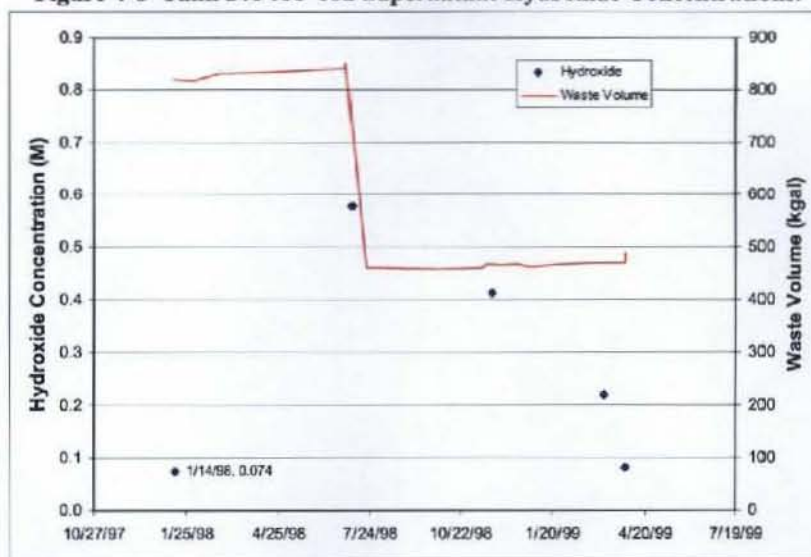


Table 4-2 Tank 241-AY-102 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Event Begin Date	Measured Value (µg/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-AY-102	Grab Sample	3/11/99	4670	0.275	0.220	HNF-1682 Rev. 0	2AY-99-2
241-AY-102	Grab Sample	3/11/99	4770	0.280		HNF-1682 Rev. 0	2AY-99-2
241-AY-102	Grab Sample	3/11/99	3520	0.207		HNF-1682 Rev. 0	2AY-99-3
241-AY-102	Grab Sample	3/11/99	3490	0.205		HNF-1682 Rev. 0	2AY-99-3
241-AY-102	Grab Sample	3/11/99	2990	0.176		HNF-1682 Rev. 0	2AY-99-4
241-AY-102	Grab Sample	3/11/99	3020	0.178		HNF-1682 Rev. 0	2AY-99-4
241-AY-102	Grab Sample	4/1/99	1620	0.095	0.082	HNF-1682 Rev. 0	2AY-99-6
241-AY-102	Grab Sample	4/1/99	1580	0.093		HNF-1682 Rev. 0	2AY-99-6
241-AY-102	Grab Sample	4/1/99	1240	0.073		HNF-1682 Rev. 0	2AY-99-7
241-AY-102	Grab Sample	4/1/99	1300	0.076		HNF-1682 Rev. 0	2AY-99-7
241-AY-102	Grab Sample	4/1/99	1290	0.076		HNF-1682 Rev. 0	2AY-99-8
241-AY-102	Grab Sample	4/1/99	1330	0.078		HNF-1682 Rev. 0	2AY-99-8

4.3.1.2 Tank 241-AY-102 Mechanistic Model Prediction

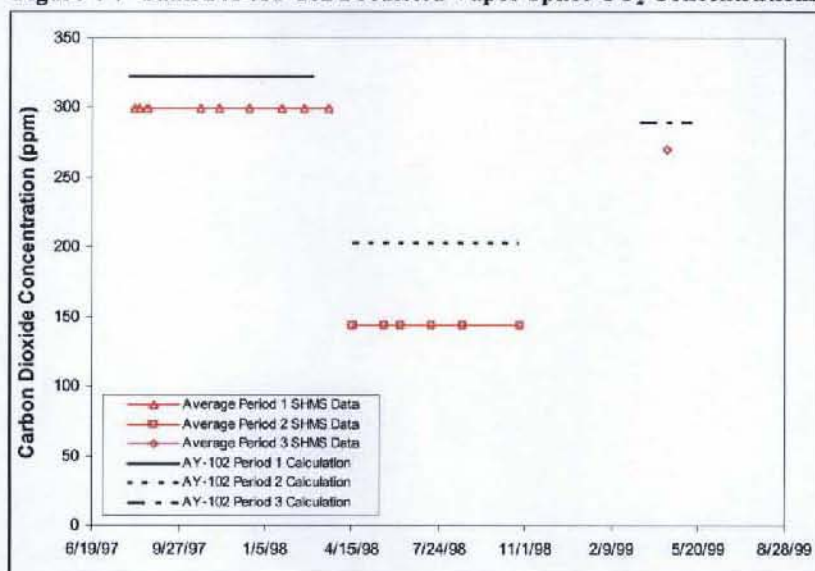
The predicted vapor space CO_2 concentrations for the three periods discussed in the previous section are shown in Figure 4-7. These are compared with the average measured data for the periods shown in Figure 4-5. The supernatant OH^- ion concentration for period 1 is 0.074 M. The low OH^- ion concentration results in higher CO_2 in the aqueous phase. This increases the CO_2 concentration on the air side of the vapor/liquid interface. The mass transfer of CO_2 from the bulk air is proportional to the CO_2 concentration difference between the bulk air and the interface. Therefore, the mass transfer of CO_2 from the bulk air is limited on the vapor side. This results in a predicted CO_2 concentration above 300 ppm which agrees well with the average measured data.

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The predicted vapor space CO₂ concentration for the second period is shown in Figure 4-7. The supernatant OH⁻ ion concentration ranges from 0.58 M to 0.41 M over the period (Figure 4-6). The higher OH⁻ ion concentration reduces the aqueous CO₂ concentration. The CO₂ absorption rate becomes limited by the supply of ventilation air. This results in a lower vapor space CO₂ concentration. The predicted concentration is near 200 ppm. This agrees reasonably well with the average measured data value of 144 ppm. Thus, the increased supernatant OH⁻ ion concentration results in a lower vapor space CO₂ concentration.

The predicted vapor space CO₂ concentration for the third period is shown in Figure 4-7. The supernatant OH⁻ ion concentration is 0.082 M. This concentration is higher than period 1 but lower than the second period. The predicted and measured vapor space CO₂ concentrations are between the values for period 1 and period 2 as expected. The predicted value is 290 ppm which agrees well with the average measured value of 270 ppm.

Figure 4-7 Tank 241-AY-102 Predicted Vapor Space CO₂ Concentrations.



The vapor space CO₂ concentration is well predicted by the mechanistic depletion model. The model predicts the difference in vapor space CO₂ concentration observed in the measured data.

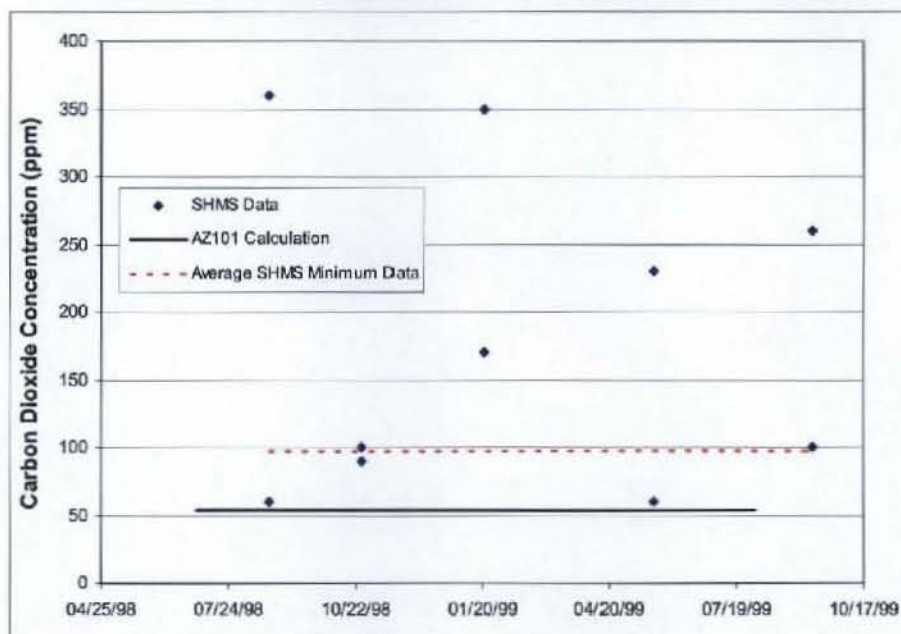
4.3.2 Tank 241-AZ-101 Carbon Dioxide Data Evaluation

Measured vapor space CO₂ concentrations for Tank 241-AZ-101 are shown in Figure 4-8 (TWINS 2007). These data were measured from August 1998 to September 1999. Duplicate values were evaluated for each sample time. The data shows a large difference for each measurement time. The reason for this measurement difference is not known. The higher values were not used for the evaluation.

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The Tank 241-AZ-101 hydroxide depletion model predictions presented in Section 3.2.10 apply to the measurement period shown in Figure 4-8 and were used for the vapor space CO₂ concentration evaluation. Figure 3-27 shows that the supernatant OH⁻ ion concentration is above 0.6 M. The CO₂ absorption is limited by the ventilation air flow rate. The predicted vapor space CO₂ concentration shown in Figure 4-8 is 54 ppm. The average for the minimum of the measured data at each sample time is 97 ppm. Therefore, the predicted vapor space CO₂ concentration agrees reasonable well with the minimum measured data.

Figure 4-8 Tank 241-AZ-101 Measured Vapor Space CO₂ Concentrations.

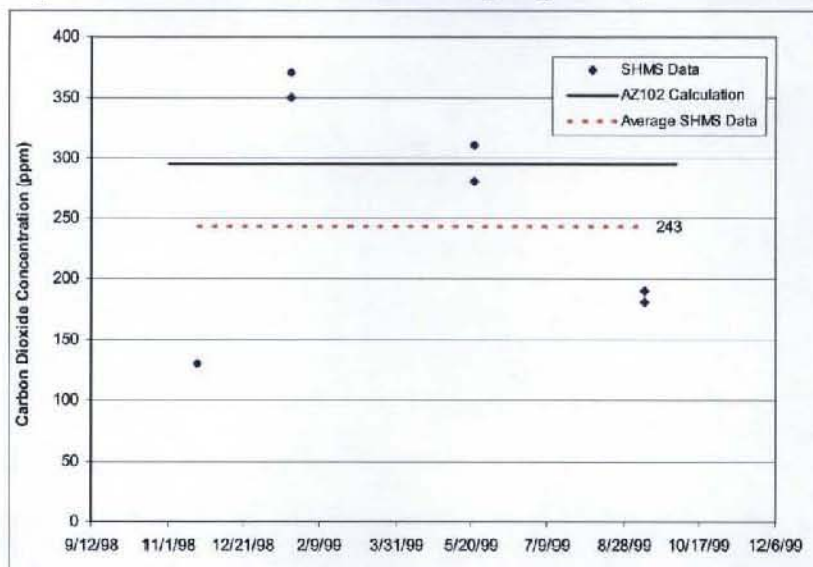


4.3.3 Tank 241-AZ-102 Carbon Dioxide Data Evaluation

Measured vapor space CO₂ concentrations for Tank 241-AZ-102 are shown in Figure 4-9 (TWINS 2007). These data were measured from November 1998 to September 1999. The duplicated data for this data set are much more consistent than the Tank 241-AZ-101 data.

The parameters for the Tank 241-AZ-102 hydroxide depletion model predictions presented in Section 3.2.11 were used for this evaluation. Figure 3-29 shows the supernatant OH⁻ ion concentration. The measured OH⁻ ion concentration was near 0.02 M during the period shown in Figure 4-9. The low supernatant OH⁻ ion concentration results in buffering which increases the aqueous CO₂ concentration and reduces the CO₂ mass transfer from the bulk air to the air/liquid interface. The predicted vapor space CO₂ concentration shown in Figure 4-9 is 295 ppm. The average measured data during this period is 243 ppm. Therefore, the predicted vapor space CO₂ concentration agrees well with the average measured data.

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Figure 4-9 Tank 241-AZ-102 Measured Vapor Space CO₂ Concentrations.**4.3.4 AWF Ventilation Carbon Dioxide Data Evaluation****4.3.4.1 AWF Data**

The measured CO₂ concentration in the AWF ventilation outlet stream in August 2000 is shown in Figure 4-10 (TWINS 2007). The samples were collected using SUMMA[™] canisters. The average measured CO₂ concentration is 325 ppm. This air stream incorporates the ventilation air for Tanks 241-AY-101, 241-AY-102, 241-AZ-101 and 241-AZ-102. The CO₂ evaluation for Tanks 241-AZ-101 and 241-AZ-102 presented in Section 4.3.2 and 4.3.3 were used for the AWF ventilation evaluation since the tank conditions for August 2000 are expected to be similar to the individual tank conditions for the AZ tanks. The vapor space/supernatant temperature difference and ventilation flow rates for the previous Tanks 241-AY-101 and 241-AY-102 evaluations (Sections 3.2.7 and 3.2.8) were used for the evaluation of the AWF ventilation CO₂ data. The supernatant OH⁻ ion concentrations for the two 241-AY Farm tanks are shown in Table 4-3 (TWINS 2007). The supernatant OH⁻ ion concentration for both tanks is low during August 2000. The waste volume and supernatant concentrations for the two 241-AY Farm tanks are shown in Figures 4-11 and 4-12 (TWINS 2007).

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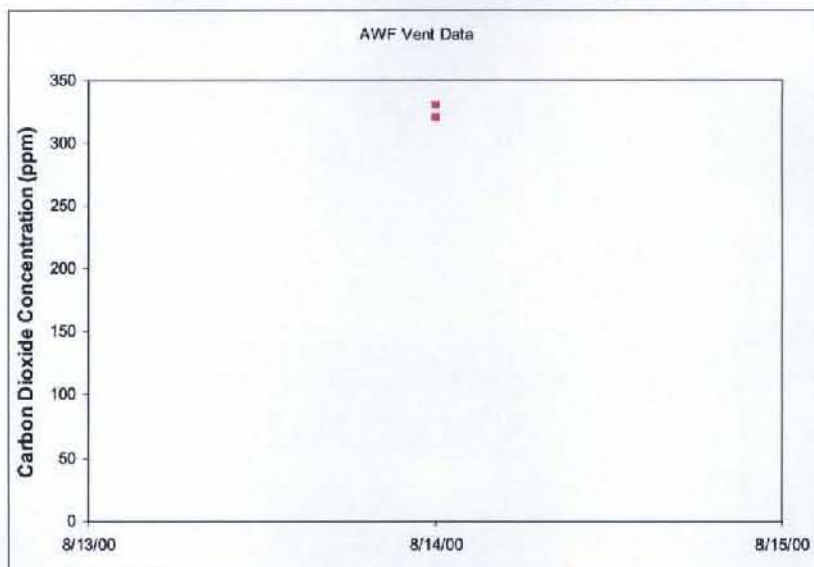
Figure 4-10 AWF Ventilation System CO₂ Data.

Table 4-3 Tank 241-AY-101 and 241-AY-102 Hydroxide Data.

Tank Name	Aggregation Level	Sample Event Begin Date	Measured pH	Calculated OH ⁻ Molar Concentration	Location of Document
241-AY-101	Core Composite	1/19/2000	9.79	6.17E-05	HNF-1710 Rev. 0
241-AY-101	Core Composite	1/19/2000	9.76	5.75E-05	HNF-1710 Rev. 0
241-AY-101	Core Composite	1/19/2000	9.4	2.51E-05	HNF-1710 Rev. 0
241-AY-101	Core Composite	1/28/2000	9.76	5.75E-05	HNF-1710 Rev. 0
241-AY-101	Core Composite	1/28/2000	9.75	5.62E-05	HNF-1710 Rev. 0
241-AY-101	Core Composite	1/28/2000	9.76	5.75E-05	HNF-1710 Rev. 0
241-AY-102	Grab Sample	11/29/2000	12.07	0.012	FH-0100790 Reissue
241-AY-102	Grab Sample	11/29/2000	12.07	0.012	FH-0100790 Reissue
241-AY-102	Grab Sample	11/29/2000	12.06	0.011	FH-0100790 Reissue
241-AY-102	Grab Sample	11/29/2000	12.13	0.013	FH-0100790 Reissue
241-AY-102	Grab Sample	11/29/2000	12.12	0.013	FH-0100790 Reissue
241-AY-102	Grab Sample	11/29/2000	12.08	0.012	FH-0100790 Reissue
241-AY-102	Grab Sample	11/29/2000	12.07	0.012	FH-0100790 Reissue

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Figure 4-11 Tank 241-AY-101 Hydroxide Data.

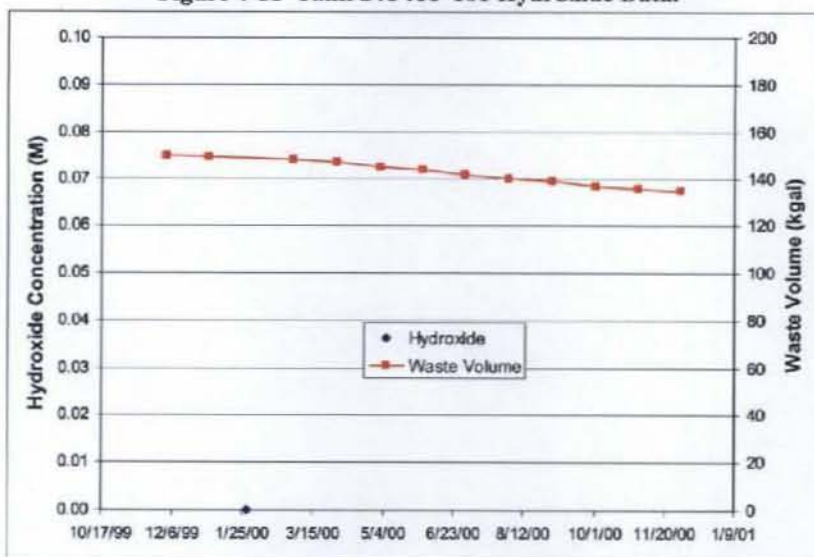
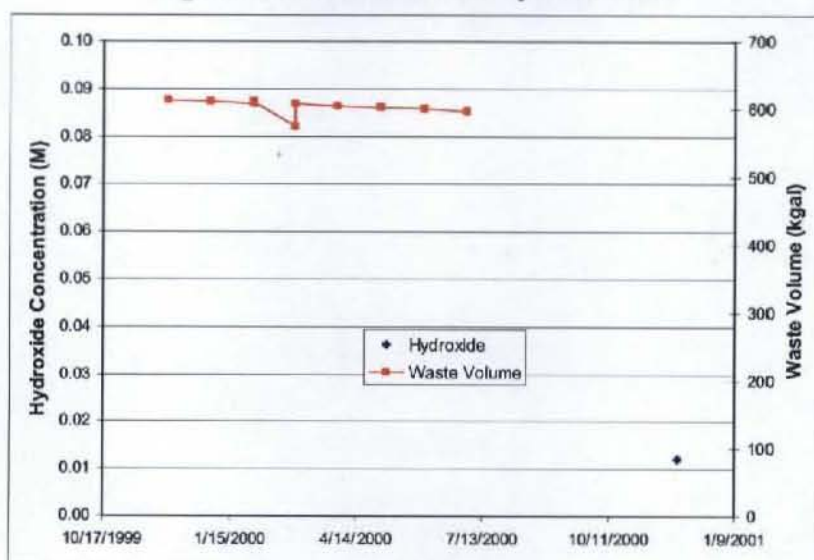


Figure 4-12 Tank 241-AY-102 Hydroxide Data.



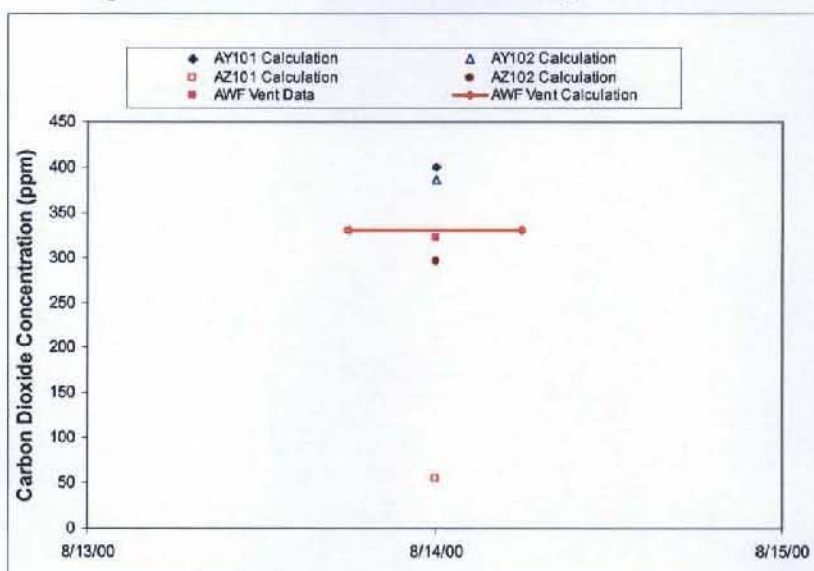
4.3.4.2 AWF Ventilation Carbon Dioxide Evaluation

The vapor space CO₂ concentration was predicted for each of the AWF tanks using the mechanistic depletion model. The vapor space CO₂ concentration is high for Tanks 241-AY-101 and 241-AY-102 because of the low supernatant OH⁻ ion concentrations. The vapor space CO₂ concentrations are much lower for Tanks 241-AZ-102 and 241-AZ-102. However, the

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ventilation flow rate for these tanks is much lower than the two 241-AY Farm tanks (see Section 3.2). The weighted average of the predicted tank values using the individual tank ventilation rates is shown in Figure 4-13. The predicted value is 333 ppm. This agrees with the measured value of 325 ppm.

Figure 4-13 AWF Ventilation Predicted CO₂ Concentration.



4.3.5 Tank 241-SY-101

The measured Tank 241-SY-101 vapor space CO₂ concentration during April 1993 is shown in Figure 4-14 (TWINS 2007). The average measured CO₂ concentration is 360 ppm. The supernatant OH⁻ ion concentration is shown in Figure 4-15 and Table 4-4 (TWINS 2007). The OH⁻ ion concentration average is 1.55 M.

Figure 4-16 shows the waste temperature profile for Tank 241-SY-101 in May 1993 (TWINS 2007). There is a steep temperature gradient near the supernatant surface caused by a surface crust. The crust thickness is estimated to be 16 in. based upon the waste level and the elevation of the 19th thermocouple. Mass transfer through the crust is assumed to be limited to molecular diffusion. A number of parameters related to diffusion through the crust are not known, including the porosity of the crust. The species diffusion coefficients may also be affected by the crust. Several of the twenty-eight DSTs have any appreciable crust. No attempt is made to develop a mechanistic treatment of the crust, because of the limited number of tanks with crusts. An empirical approach is taken. The crust thickness is estimated from temperature data and the porosity is assumed to be small. The small porosity may account for other unknown parameters such as the diffusion coefficient. A porosity of 0.02 is assumed for Tank 241-SY-101. This value provides reasonable agreement with the CO₂ data for Tank 241-SY-101. This same value is then used for all tanks with a surface crust with the exception of Tank 241-SY-103 discussed in Section 4.3.7. This empirical approach provides a

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reasonable prediction of the OH^- ion depletion rate for the limited number of tanks with surface crusts.

Figure 4-16 shows that there are no vapor space temperatures available for the Riser 018 thermocouple tree. Thus the supernatant/vapor space temperature difference for Tank 241-SY-103 (Section 4.3.7) is used. The two tanks have about the same heat load and the ventilation flow rates and supernatant temperatures are about the same. A value of 2°F is used. The predicted vapor space CO_2 concentration is not sensitive to this value since the mass transfer is limited by the crust.

Figure 4-14 Tank 241-SY-101 Vapor Space CO_2 Data.

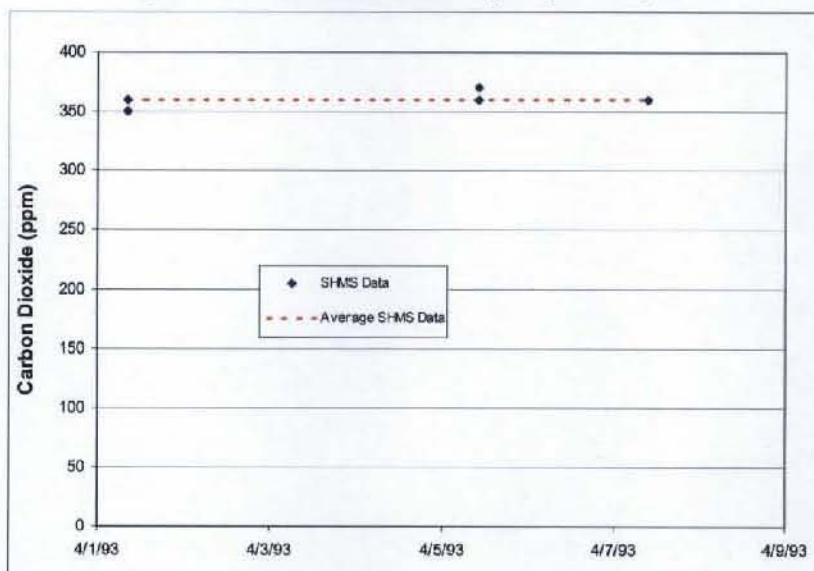
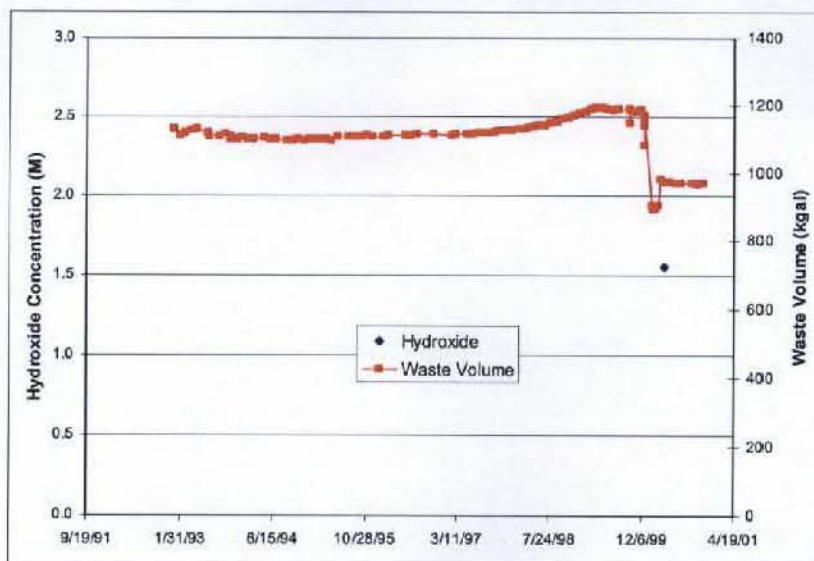


Figure 4-15 Tank 241-SY-101 Hydroxide Data.

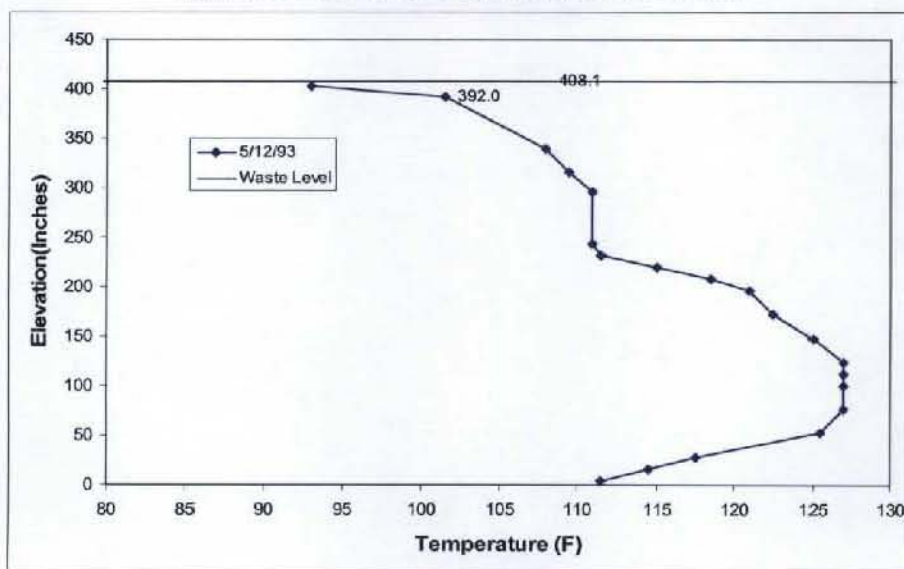


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Table 4-4 Tank 241-SY-101 Measured Hydroxide Concentrations.

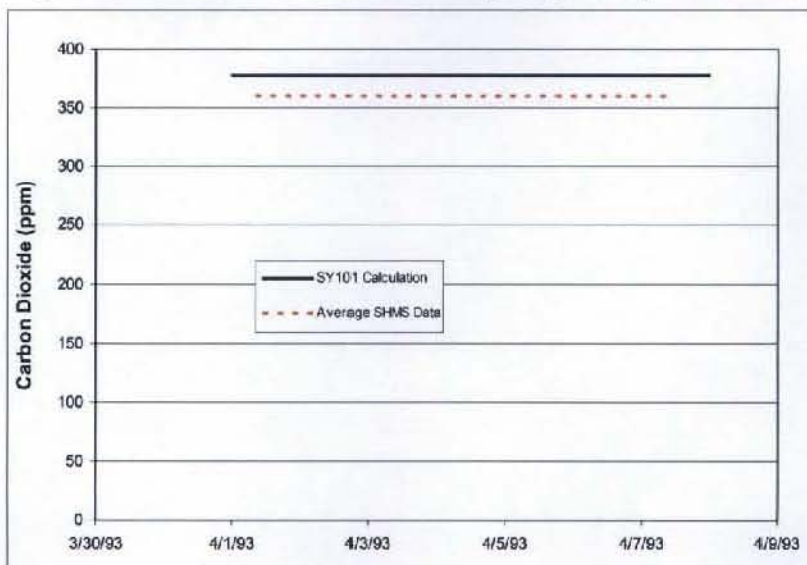
Tank Name	Aggregation Level	Sample Event Begin Date	Measured Value ($\mu\text{g/mL}$)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-SY-101	Grab Sample	4/3/00	26300	1.55	1.55	HNF-1702 Rev. 0	1SY-00-2
241-SY-101	Grab Sample	4/3/00	22000	1.29		HNF-1702 Rev. 0	1SY-00-1
241-SY-101	Grab Sample	4/3/00	25800	1.52		HNF-1702 Rev. 0	1SY-00-2
241-SY-101	Grab Sample	4/3/00	21700	1.28		HNF-1702 Rev. 0	1SY-00-1
241-SY-101	Grab Sample	4/6/00	27200	1.60		HNF-1702 Rev. 0	1SY-00-3
241-SY-101	Grab Sample	4/6/00	28600	1.68		HNF-1702 Rev. 0	1SY-00-5
241-SY-101	Grab Sample	4/6/00	28200	1.66		HNF-1702 Rev. 0	1SY-00-4
241-SY-101	Grab Sample	4/6/00	27500	1.62		HNF-1702 Rev. 0	1SY-00-3
241-SY-101	Grab Sample	4/6/00	28000	1.65		HNF-1702 Rev. 0	1SY-00-5
241-SY-101	Grab Sample	4/6/00	28000	1.65		HNF-1702 Rev. 0	1SY-00-4

Figure 4-16 Tank 241-SY-101 Temperature Profile.



The predicted vapor space CO_2 concentration for Tank 241-SY-101 during April 1993 is compared with the average measured data in Figure 4-17. The predicted and measured vapor space CO_2 concentrations are in good agreement using the empirical value for the crust porosity. The mass transfer of OH^- ion from the bulk supernatant is limited by molecular diffusion through the surface crust. This results in a high vapor space CO_2 concentration. Good results are obtained for other tanks with surface crusts without changing the empirical value for the crust porosity chosen for Tank 241-SY-101. The evaluation of Tank 241-SY-101 is used to develop the empirical crust model. The results are not included in the benchmark summary provided in Section 4.3.23.

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Figure 4-17 Predicted Tank 241-SY-101 Vapor Space CO₂ Concentration.

4.3.6 Tank 241-SY-102

The measured Tank 241-SY-102 vapor space CO₂ concentration during 1998 is shown in Figure 4-18 (TWINS 2007). Two periods will be evaluated. The first is from March to August of 1998 and the second in September and October of 1998. The average measured CO₂ concentration for the first period is 297 ppm while the average data for the second period is 122 ppm. The supernatant OH⁻ ion concentration is shown in Figure 4-19 and Table 4-5. The supernatant OH⁻ ion concentration is 0.074M for the first portion of the data shown in Figure 4-18 and 0.18 M during the second portion of the CO₂ measurements.

The waste temperature profile for Tank 241-SY-102 in October 1998 is shown in Figure 4-20 (TWINS 2007). Supernatant and vapor space temperatures are shown in Figure 4-21 (TWINS 2007). The average supernatant/vapor space temperature difference for the first evaluation period is small, less than 1 °F. A value of 0.1 °F is used for the evaluation. The vapor space temperature (TC17) exceeds the supernatant temperature (TC11) for some of the first evaluation period. The average supernatant/vapor space temperature difference increased significantly during the second evaluation period. The vapor space CO₂ data were measured near the transition into the larger temperature differences. The temperature difference for the second period at the time of the CO₂ measurements is assumed to be at least 1 °F.

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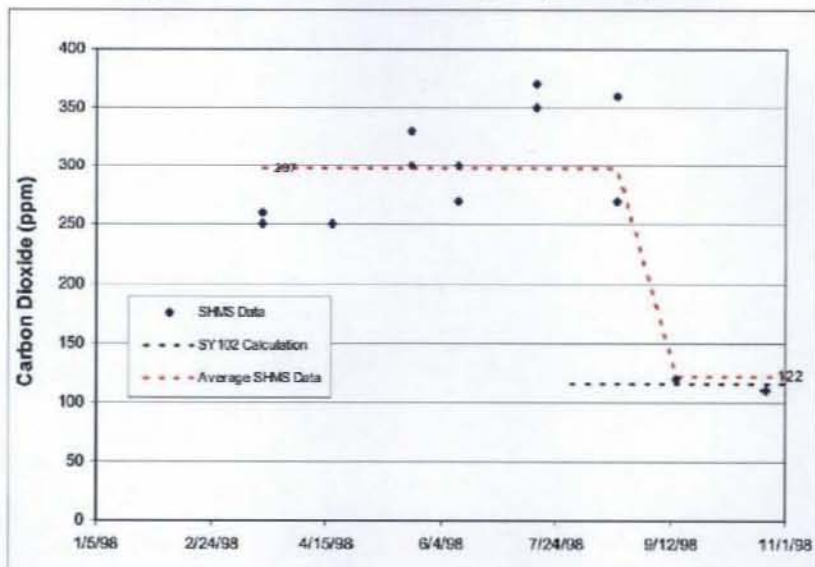
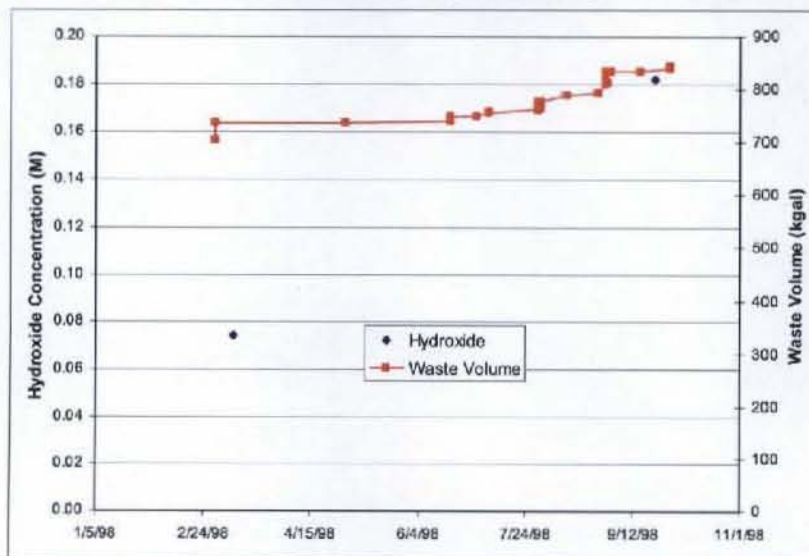
Figure 4-18 Tank 241-SY-102 Vapor Space CO₂ Data.

Figure 4-19 Tank 241-SY-102 Supernatant Hydroxide Data.



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Table 4-5 Tank 241-SY-102 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Event Begin Date	Measured Value (µg/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-SY-102	Grab Sample	3/10/98	1170	0.069	0.074	HNF-SD-WM-DP-307, Rev. 0	2SY-98-4
241-SY-102	Grab Sample	3/10/98	1080	0.063		HNF-SD-WM-DP-307, Rev. 0	2SY-98-2
241-SY-102	Grab Sample	3/10/98	1650	0.097		HNF-SD-WM-DP-307, Rev. 0	2SY-98-1
241-SY-102	Grab Sample	3/10/98	1180	0.069		HNF-SD-WM-DP-307, Rev. 0	2SY-98-3
241-SY-102	Grab Sample	3/10/98	1160	0.068		HNF-SD-WM-DP-307, Rev. 0	2SY-98-4
241-SY-102	Grab Sample	3/10/98	1080	0.063		HNF-SD-WM-DP-307, Rev. 0	2SY-98-2
241-SY-102	Grab Sample	3/10/98	1590	0.093		HNF-SD-WM-DP-307, Rev. 0	2SY-98-1
241-SY-102	Grab Sample	3/10/98	1180	0.069		HNF-SD-WM-DP-307, Rev. 0	2SY-98-3
241-SY-102	Grab Sample	9/22/98	4830	0.284	0.182	HNF-1658 Rev. 0	2SY-98-5
241-SY-102	Grab Sample	9/22/98	2960	0.174		HNF-1658 Rev. 0	2SY-98-8
241-SY-102	Grab Sample	9/22/98	2300	0.135		HNF-1658 Rev. 0	2SY-98-6
241-SY-102	Grab Sample	9/22/98	2600	0.153		HNF-1658 Rev. 0	2SY-98-7
241-SY-102	Grab Sample	9/22/98	4340	0.255		HNF-1658 Rev. 0	2SY-98-5
241-SY-102	Grab Sample	9/22/98	2790	0.164		HNF-1658 Rev. 0	2SY-98-8
241-SY-102	Grab Sample	9/22/98	2430	0.143		HNF-1658 Rev. 0	2SY-98-6
241-SY-102	Grab Sample	9/22/98	2500	0.147		HNF-1658 Rev. 0	2SY-98-7
241-SY-102	Grab Sample	4/11/00	10400	0.61	1.17	HNF-1705 Rev. 0	2SY-00-6
241-SY-102	Grab Sample	4/11/00	10800	0.63		HNF-1705 Rev. 0	2SY-00-6
241-SY-102	Grab Sample	4/11/00	20100	1.18		HNF-1705 Rev. 0	2SY-00-7
241-SY-102	Grab Sample	4/11/00	21100	1.24		HNF-1705 Rev. 0	2SY-00-7
241-SY-102	Grab Sample	4/11/00	20300	1.19		HNF-1705 Rev. 0	2SY-00-8
241-SY-102	Grab Sample	4/11/00	21800	1.28		HNF-1705 Rev. 0	2SY-00-8
241-SY-102	Grab Sample	4/11/00	13800	0.81		HNF-1705 Rev. 0	2SY-00-9
241-SY-102	Grab Sample	4/11/00	13500	0.79		HNF-1705 Rev. 0	2SY-00-9
241-SY-102	Grab Sample	4/11/00	23500	1.38		HNF-1705 Rev. 0	2SY-00-9
241-SY-102	Grab Sample	4/11/00	23100	1.36		HNF-1705 Rev. 0	2SY-00-9
241-SY-102	Grab Sample	4/11/00	24300	1.43		HNF-1705 Rev. 0	2SY-00-9
241-SY-102	Grab Sample	4/11/00	23500	1.38		HNF-1705 Rev. 0	2SY-00-9
241-SY-102	Grab Sample	4/11/00	24900	1.46		HNF-1705 Rev. 0	2SY-00-10
241-SY-102	Grab Sample	4/11/00	24300	1.43		HNF-1705 Rev. 0	2SY-00-10
241-SY-102	Grab Sample	4/11/00	15500	0.91		HNF-1705 Rev. 0	2SY-00-10
241-SY-102	Grab Sample	4/11/00	16000	0.94		HNF-1705 Rev. 0	2SY-00-10
241-SY-102	Grab Sample	4/11/00	25900	1.52		HNF-1705 Rev. 0	2SY-00-10
241-SY-102	Grab Sample	4/11/00	26000	1.53		HNF-1705 Rev. 0	2SY-00-10
241-SY-102	Grab Sample	10/3/00	13500	0.79	1.06	HNF-6051 Rev. 0	2SY-01-1
241-SY-102	Grab Sample	10/3/00	13600	0.80		HNF-6051 Rev. 0	2SY-01-1
241-SY-102	Grab Sample	10/3/00	19500	1.15		HNF-6051 Rev. 0	2SY-01-2
241-SY-102	Grab Sample	10/3/00	20200	1.19		HNF-6051 Rev. 0	2SY-01-2
241-SY-102	Grab Sample	10/3/00	20700	1.22		HNF-6051 Rev. 0	2SY-01-3
241-SY-102	Grab Sample	10/3/00	20800	1.22		HNF-6051 Rev. 0	2SY-01-3

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Figure 4-20 Tank 241-SY-102 Temperature Profile.

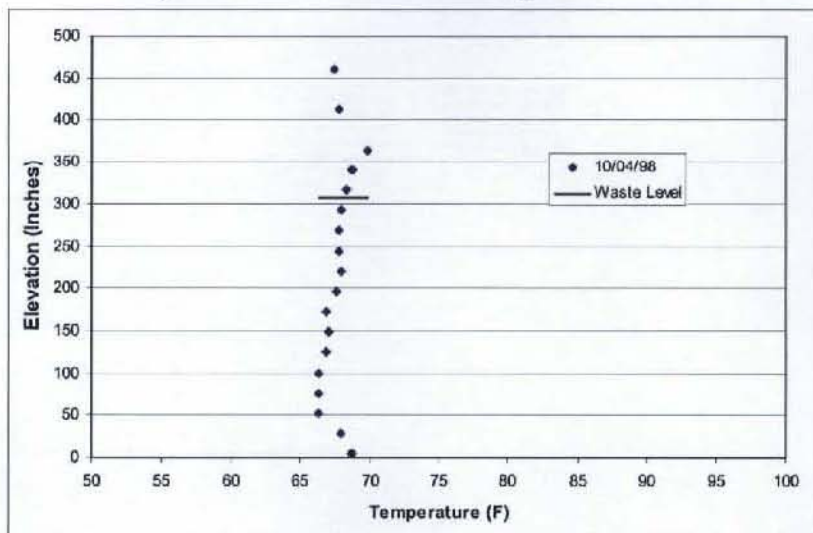
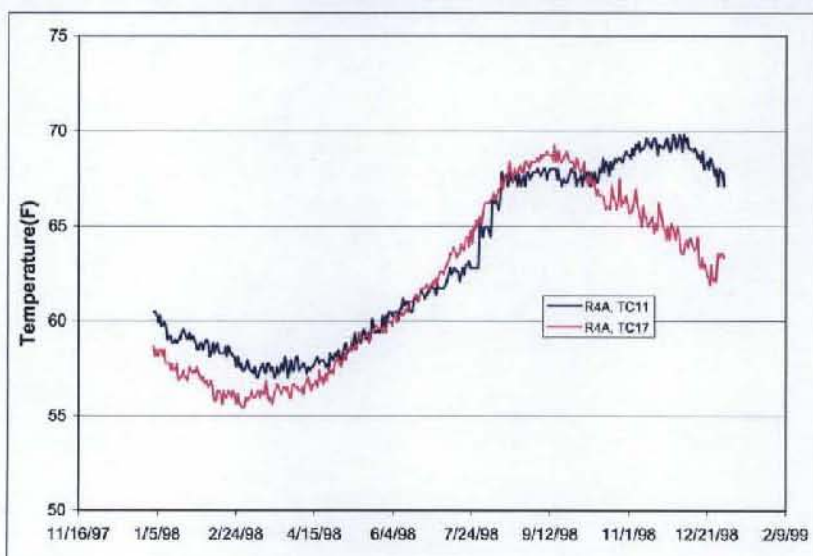
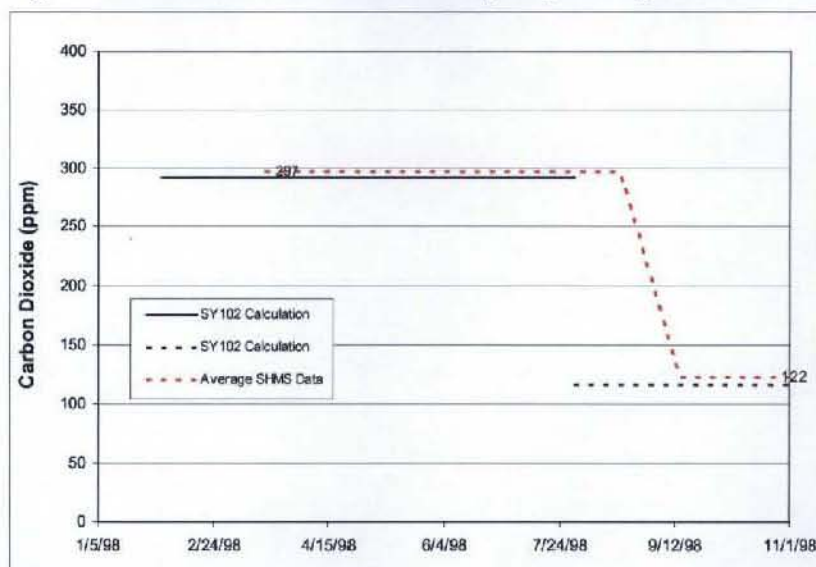


Figure 4-21 Tank 241-SY-102 Supernatant and Vapor Space Temperatures.



The predicted vapor space CO_2 concentration for Tank 241-SY-102 for the two evaluation periods is shown in Figure 4-22. There is good agreement with the predicted and measured vapor space CO_2 concentration for both evaluation periods. The vapor space CO_2 concentration is higher during the first period because the CO_2 mass transfer is limited by the small supernatant/vapor space temperature difference and the low OH^- ion concentration, which creates buffering of the OH^- ion. The vapor space CO_2 concentration for the second period decreases due to higher CO_2 absorption resulting from the greater supernatant/vapor space temperature difference and higher supernatant OH^- ion concentration.

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Figure 4-22 Predicted Tank 241-SY-102 Vapor Space CO₂ Concentration.

4.3.7 Tank 241-SY-103

The measured Tank 241-SY-103 vapor space CO₂ concentration made from September 1994 to August 1999 are shown in Figure 4-23 (TWINS 2007). A few data with values over 400 ppm were considered unrealistic and were omitted. The supernatant OH⁻ ion concentration is shown in Figure 4-24 and Table 4-6 (TWINS 2007). The supernatant OH⁻ ion concentration is near 1.7 M during the time of the CO₂ measurements.

The vapor space CO₂ concentrations in 1994 are similar to the measurements in 1998. However, the measurements of vapor space CO₂ concentration in 1995 and 1996 are significantly lower. Figures 4-25 and 4-26 show the waste temperature profile and the supernatant and vapor space temperatures (TWINS 2007). The temperature gradient near the waste surface suggests a thermal conduction limited region or crust. The mass transfer through the crust is modeled with a crust thickness and porosity. Mass transfer is assumed to occur by diffusion only. The crust thickness is approximately 26 in. (Section 5.7, Appendix B). An empirical value of 0.02 for the porosity was determined from the evaluation of Tank 241-SY-101, Section 4.3.5. This value provides reasonable agreement with the CO₂ data for Tank 241-SY-101. Core sample data indicate the presence of solids in the supernatant near the surface, HNF-7430. However, the concentration of solids is not as great as the crust for some tanks in the 241-AN Farm or 241-AW Farm. It is assumed that the porosity for Tank 241-SY-103 crust is greater than other surface crusts. Therefore the porosity is increased by an order magnitude.

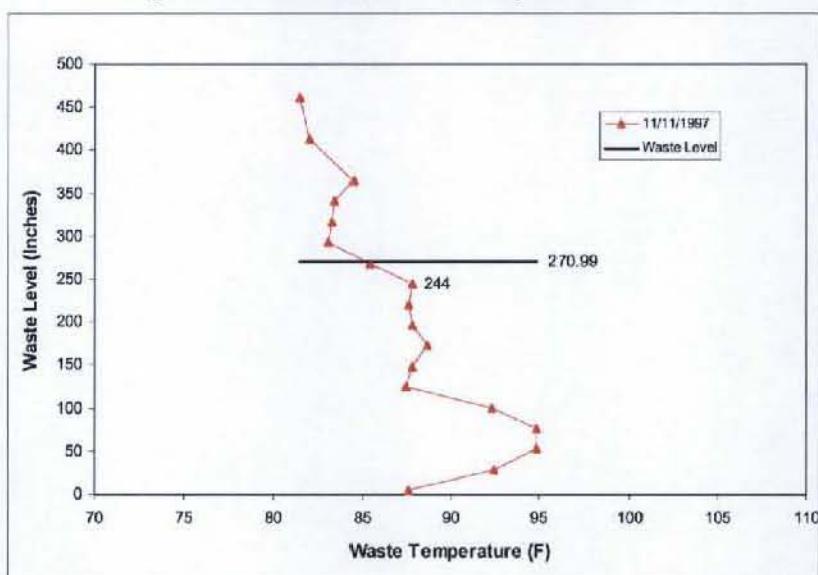
The supernatant temperature is clearly lower from late 1996 forward. This is an indication of the potential changes in ventilation flows rate of either the primary or secondary system, or both.

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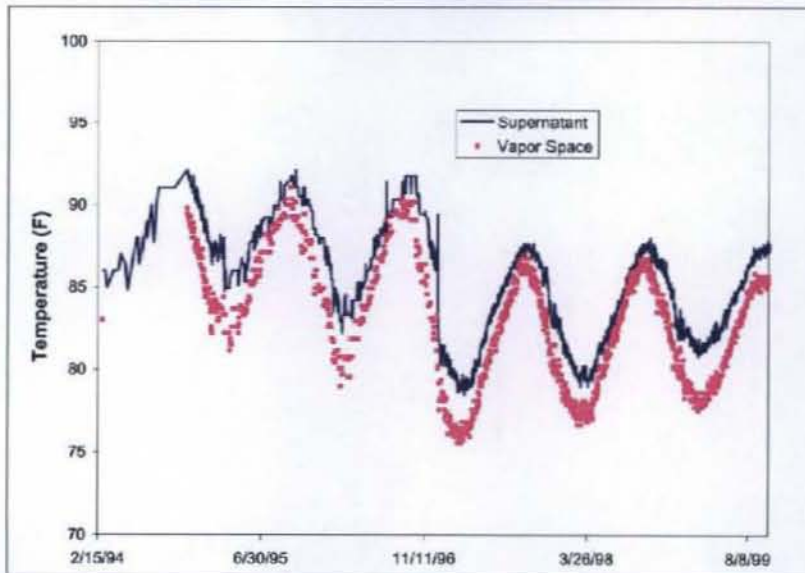
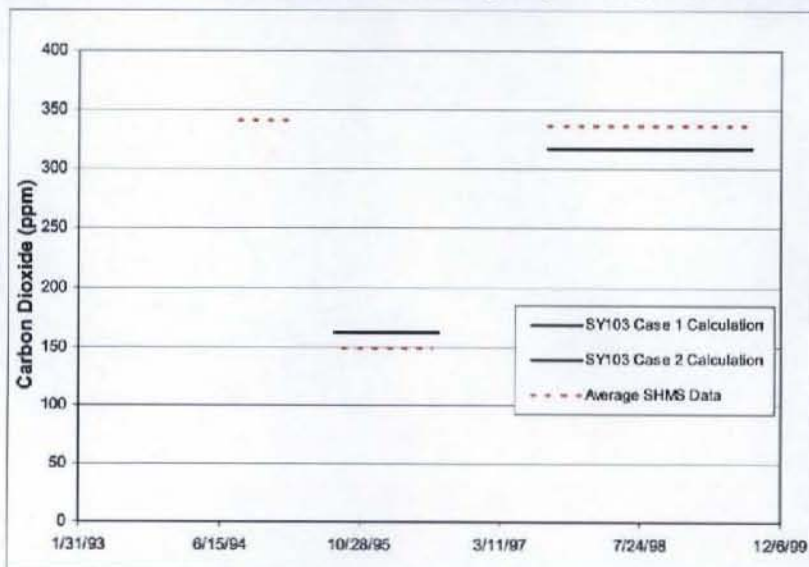
Table 4-6 Tank 241-SY-103 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Event Begin Date	Measured Value (µg/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name	Segment Name
241-SY-103	Drainable Liquid	8/19/94	28900	1.70	1.72	WHC-SD-WM-DP-074, Rev. 0	62	8
241-SY-103	Drainable Liquid	8/19/94	29600	1.74		WHC-SD-WM-DP-074, Rev. 0	62	8
241-SY-103	DL Core Composite	3/7/00	30700	1.80	1.86	HNF-7430 Rev.0		
241-SY-103	DL Core Composite	3/7/00	31600	1.86		HNF-7430 Rev.0		
241-SY-103	DL Core Composite	3/7/00	32500	1.91		HNF-7430 Rev.0		

Figure 4-25 Tank 241-SY-103 Temperature Profile.



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Figure 4-26 Tank 241-SY-103 Supernatant and Vapor Space Temperatures.**Figure 4-27 Predicted Tank 241-SY-103 Vapor Space CO₂ Concentration.**

The mechanistic depletion model is used to predict the vapor space CO₂ concentration. Two analyses cases were performed. The first analysis (case 1) assumed a normal primary ventilation flow rate of approximately 330 cfm. This analysis applies to the measured 1998 and 1999 CO₂ data shown in Figure 4-23. A second analysis (case 2) assumes that the primary ventilation flow

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is reduced by 66%. Low primary ventilation flow is a possible explanation for the lower CO₂ concentration measurements shown in Figure 4-23, but has not been confirmed. However, the hydrogen concentration during the second period is as high as 1800 ppm (TWINS 2007). This is an indication of Gas Release Events (GRE) from the waste. These GREs can increase the pressure in the vapor space, thus reducing the inlet ventilation flow rate and diluting the vapor space CO₂ concentration.

The results of the analyses are shown in Figure 4-27. The first analysis, assuming normal primary ventilation flow, agrees well with the data. The surface crust reduces the OH⁻ ion mass transfer from the bulk supernatant, which reduces the absorption of CO₂ from the ventilation air. The CO₂ absorption is limited by the liquid mass transfer, not the ventilation air supply. There is good agreement with the data using the nominal ventilation flow rate.

The flow was reduced for the second analysis parametrically to determine the flow rate that would provide the reduced CO₂ concentration observed in the data. A reduction of 66% provides good agreement with the data. The CO₂ concentration is significantly lower because the absorption rate becomes limited by the ventilation air supply. Thus, a reduced primary ventilation flow rate is a possible explanation for the reduced vapor space CO₂ concentration in 1995 and 1996, but has not been confirmed from ventilation system records. Apparent GREs during this period may offer an explanation for a reduced inlet flow rate and low CO₂ concentration.

The second analysis was parametric in nature, performed to understand the CO₂ concentration data. The results are not included in the benchmark summary provided in Section 4.3.23.

4.3.8 241-SY Farm Ventilation System Carbon Dioxide Evaluation

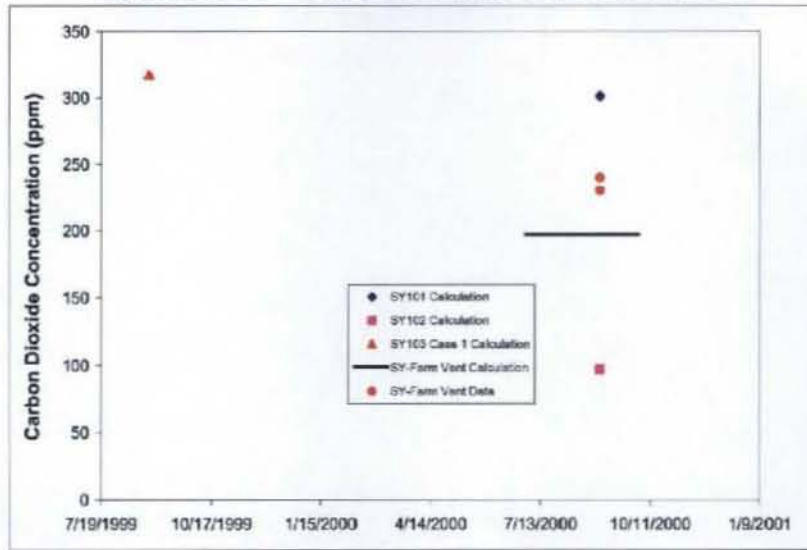
The measured CO₂ concentration in the 241-SY Farm primary ventilation system for August 30, 2000, is shown in Figure 4-28. The CO₂ concentration from the combined ventilation flow for the three 241-SY Farm tanks is near 230 ppm. The mechanistic model was used to predict the 241-SY Farm CO₂ concentration.

Figure 4-29 shows the Tank 241-SY-101 waste temperature for August 30, 2000 (TWINS 2007). Waste was transferred out of Tank 241-SY-101 late 1999 and early 2000. A comparison of Figure 4-16 and 4-29 shows that the tank heat load has been reduced, resulting in lower waste temperatures, and the crust appears to have been eliminated. The mechanistic model analyses for August 2000 is performed without a crust and a vapor space/supernatant temperature difference less than 1 °F. The OH⁻ ion concentration for this period are shown in Table 4-4.

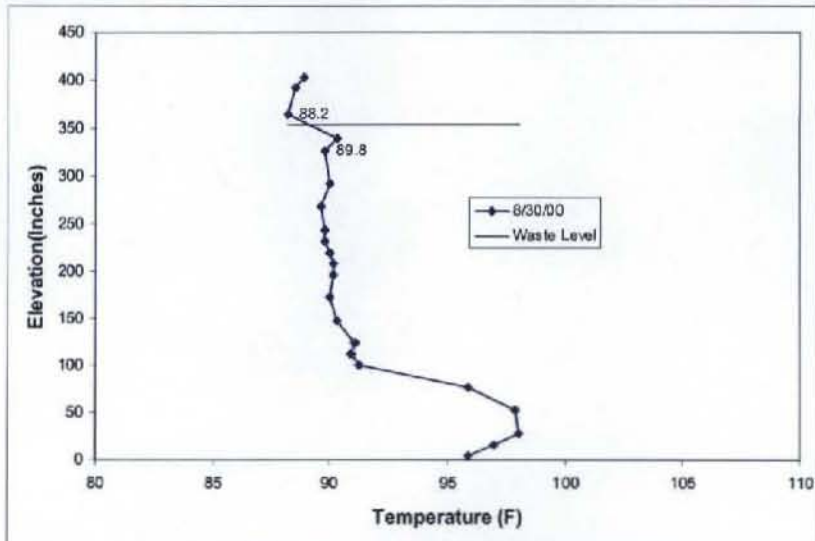
Figure 4-30 shows the Tank 241-SY-102 waste temperature profile for August 30, 2000 (TWINS 2007). There is a 2.5 °F vapor space/supernatant temperature differences. The mechanistic model calculation for the 241-SY Farm ventilation used this temperature difference and the OH⁻ ion concentration for this period shown in Table 4-5.

The Tank 241-SY-103 case 1 analyses presented in Section 4.3.7 were used for the 241-SY Farm ventilation analyses. The tank conditions in August 1999 and August 2000 are expected to be similar. The OH⁻ ion concentration for this period is shown in Table 4-6.

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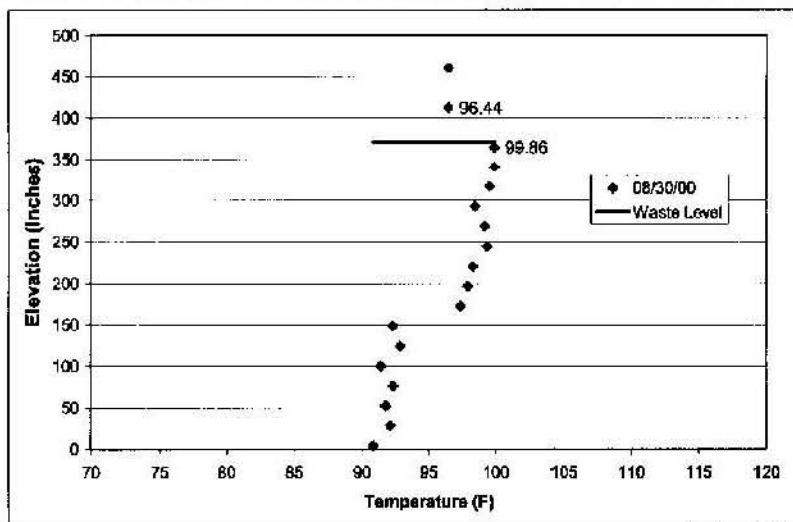
Figure 4-28 241-SY Farm Ventilation CO₂ Concentration.

Results of the mechanistic model evaluation of the 241-SY Farm ventilation system CO₂ data are shown in Figure 4-28. The predicted ventilation air CO₂ concentration of near 200 ppm agrees well with the average data.

Figure 4-29 Tank 241-SY-101 August 30, 2000, Waste Temperature Profile.

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Figure 4-30 Tank 241-SY-102 August 30, 2000, Waste Temperature Profile.



4.3.9 Tank 241-AW-101

The measured Tank 241-AW-101 vapor space CO₂ concentrations and waste level are shown in Figure 4-31 (TWINS 2007). If the measured CO₂ concentrations reported were less than the detection limit, the detection limit value was used. The vapor space CO₂ concentrations increase significantly towards the end of 1996. This may be due to changes in the ventilation system flow rates. Ventilation system operation with inlet flow control stations was initiated in 1996 as depicted by the step increase in CO₂ concentration, Figure 4-31. The inlet flow rates through the flow control stations are shown in Table 4-7, RPP-11731. An average stack flow rate for the 241-AW Farm is also shown in Table 4-7. The estimated total flow rate per tank assumes that the in-leakage (measured stack flow minus the total flow control station flows) is equally distributed. The total ventilation flow rate for Tank 241-AW-101 after the flow control station was installed is 229 cfm. Prior to 1996 the inlet flow occurred through in-leakage only. The total flow rate would have been lower because of the higher flow resistance of in-leakage sites. Tank 241-AW-101 is one of the farthest tanks from the ventilation system exhausters and should have had a flow less than the average. The average flow rate per tank with the flow control station (Table 4-7) is 160 cfm. Prior to 1996 the Tank 241-AW-101 flow should have been less than 160 cfm. For these reasons, the flow control station flow for Tank 241-AW-101 after 1996 could be more than double the inlet flow rate prior to 1996.

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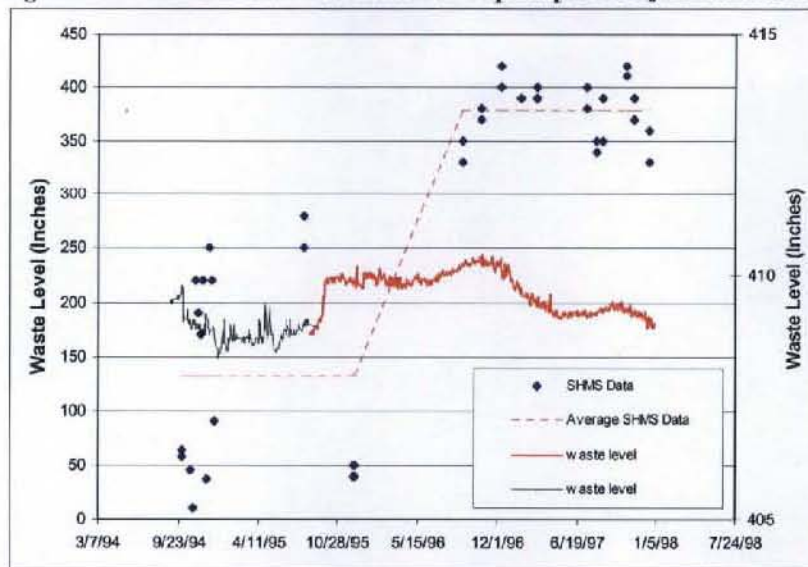
Figure 4-31 Tank 241-AW-101 Measured Vapor Space CO₂ Concentrations.

Table 4-7 241-AW Farm Primary Ventilation Flow Rates.

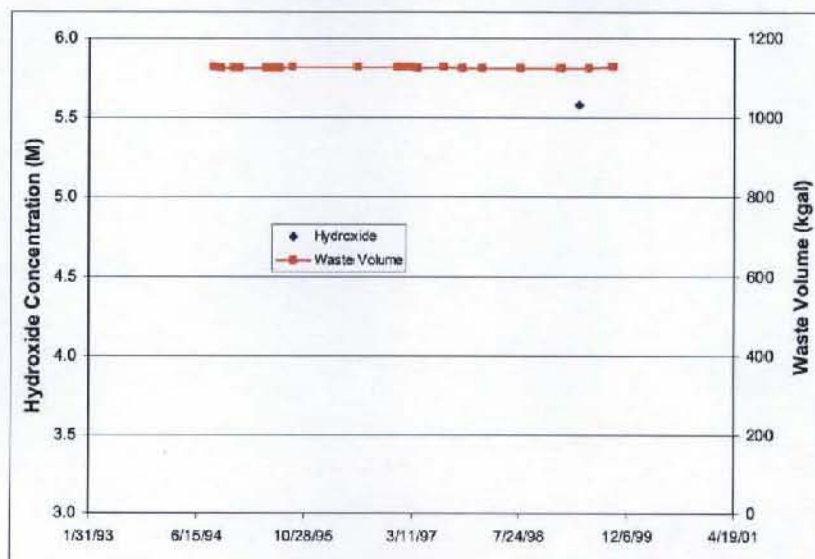
	Flow Control Station Flow (cfm)	Total Flow (cfm)
AW101	125	229
AW102	70	174
AW103	35	139
AW104	35	139
AW105	35	139
AW106	35	139
Total Flow Control Station Flow (cfm)	335	
Total Farm Flow (cfm)	960	

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The supernatant OH^- ion concentration is shown in Figure 4-32 and Table 4-8 (TWINS 2007). The OH^- ion concentration is nearly 6.0 M. The August 31, 1998, waste temperature profile for Tank 241-AW-101 is shown in Figure 4-33 (TWINS 2007). The large temperature gradient near the waste surface shows the presence of a surface crust. This crust is on the order of 30 in, almost two core segments thick, WHC-SD-WM-DP-192. Mass transfer through the crust is assumed to be by diffusion only.

Figure 4-34 shows the Tank 241-AW-101 supernatant and vapor space temperatures (TWINS 2007). The average temperature difference exceeds 10 °F. This is a consequence of the thick surface crust which Figure 4-33 shows is at least 30 in thick based upon the temperature gradient near the waste surface. The mass transfer through the crust is modeled with a crust thickness and porosity. Mass transfer is assumed to occur by diffusion only. An empirical value of 0.02 for the porosity was determined from the evaluation of Tank 241-SY-101, Section 4.3.5. This value provides reasonable agreement with the CO_2 data for Tank 241-SY-101. This same value is then used for all tanks with a surface crust except for Tank 241-SY-103 discussed in Section 4.3.7. This empirical approach provides a reasonable prediction of the OH^- ion depletion rate for the limited number of tanks with surface crust.

Figure 4-32 Tank 241-AW-101 Supernatant Hydroxide Data.

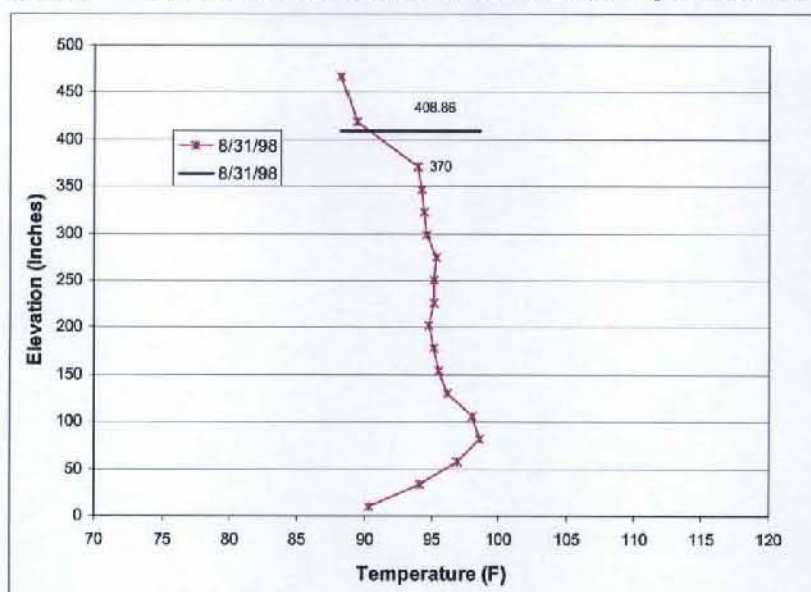


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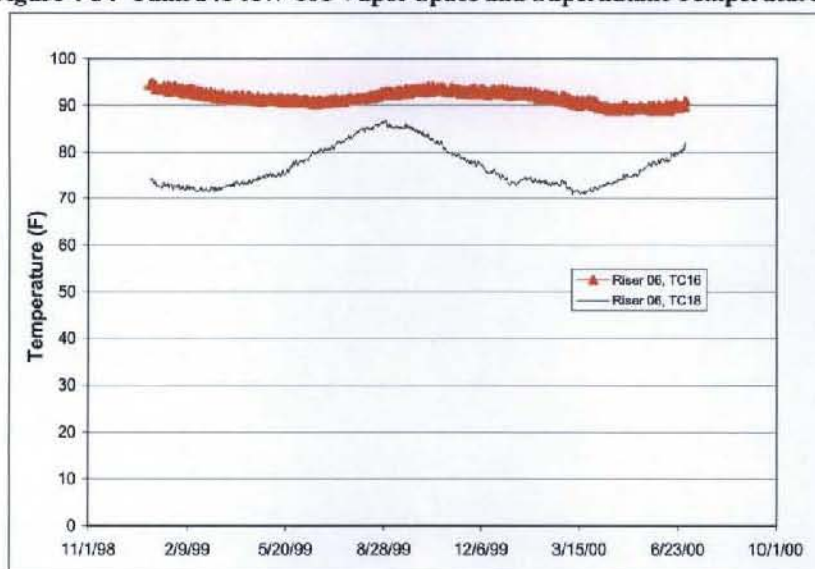
Table 4-8 Tank 241-AW-101 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Analysis Date	Measured Value ($\mu\text{g/mL}$)	Molarity	Average Value (M)	Document Location
241-AW-101	Supernate Composite	4/21/99	94300	5.55	5.59	HNF-1652 Rev. 0
241-AW-101	Supernate Composite	4/21/99	94300	5.55		HNF-1652 Rev. 0
241-AW-101	Supernate Composite	4/21/99	96300	5.66		HNF-1652 Rev. 0

Figure 4-33 Tank 241-AW-101 August 31, 1998, Waste Temperature Profile.

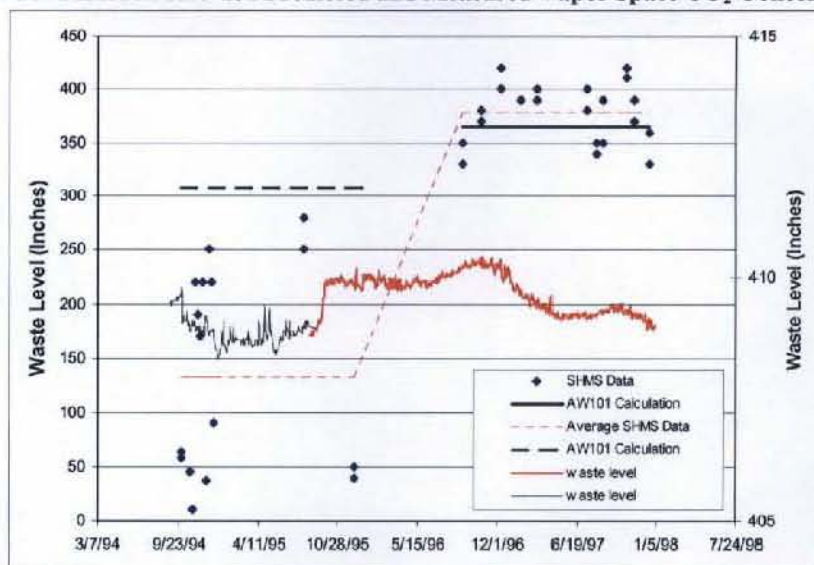


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Figure 4-34 Tank 241-AW-101 Vapor Space and Supernatant Temperatures.

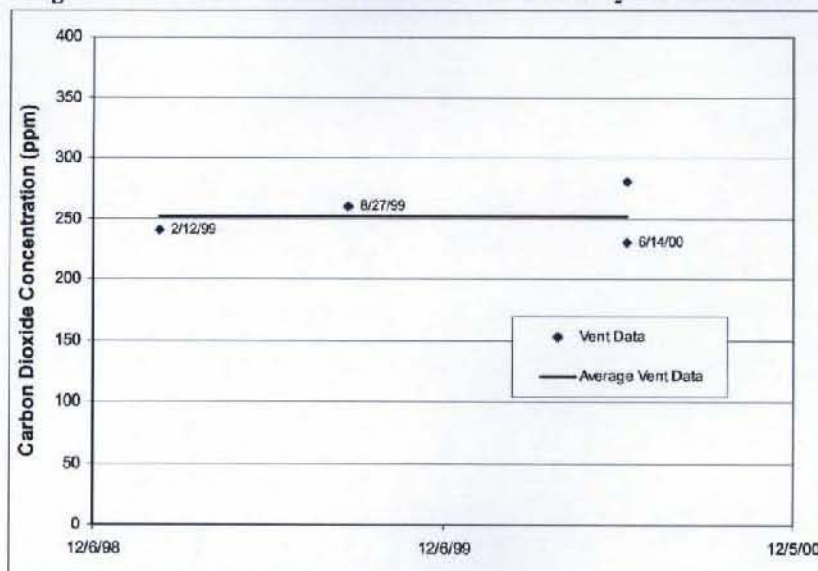
Two cases are analyzed using the mechanistic depletion model. The first applies to the ventilation system operation after the installation of the flow control station. The ventilation flow rate shown in Table 4-7 was used for the analyses. The second case used a ventilation flow rate one-third the value shown in Table 4-7. The purpose of the second analysis is to assess the effect of reduced ventilation flow. The results of the mechanistic model analyses are shown in Figure 4-35. There is good agreement between the measured and predicted vapor space CO₂ concentration for the data measured after late 1996. This applies to the current ventilation system configuration. This should be representative of the current tank conditions. The second analyses, which used the reduce ventilation system flow, is somewhat lower than the case 1 analyses but significantly higher than the average measured data. It is difficult to know the actual ventilation flow rate for this period. The actual rate may be even lower than estimated, which would result in even lower predicted vapor space CO₂ concentrations. Thus, differences in ventilation flow provide a possible explanation for the differences in vapor space CO₂ concentrations shown in Figure 4-35. The second analysis is parametric in nature, performed to better understand the vapor space CO₂ concentration data. The results are not included in the benchmark summary provided in Section 4.3.23.

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Figure 4-35 Tank 241-AW-101 Predicted and Measured Vapor Space CO₂ Concentrations.

4.3.10 241-AW Farm Ventilation System Carbon Dioxide Evaluation

The measured 241-AW Farm ventilation system CO₂ concentrations are shown in Figure 4-36 (TWINS 2007). The average measured data is near 250 ppm. The mechanistic depletion model was used to evaluate the vapor space CO₂ concentrations for all the 241-AW Farm tanks. The ventilation flow weighted average of all the tanks is compared with the measured ventilation CO₂ concentrations. The ventilation flow rates shown in Table 4-7 were used for the evaluation of the 241-AW Farm CO₂ data. The estimated total flow rate per tank assumes that the in-leakage (measured stack flow minus the total flow control station flows) is equally distributed.

Figure 4-36 241-AW Farm Ventilation Measured CO₂ Concentrations.

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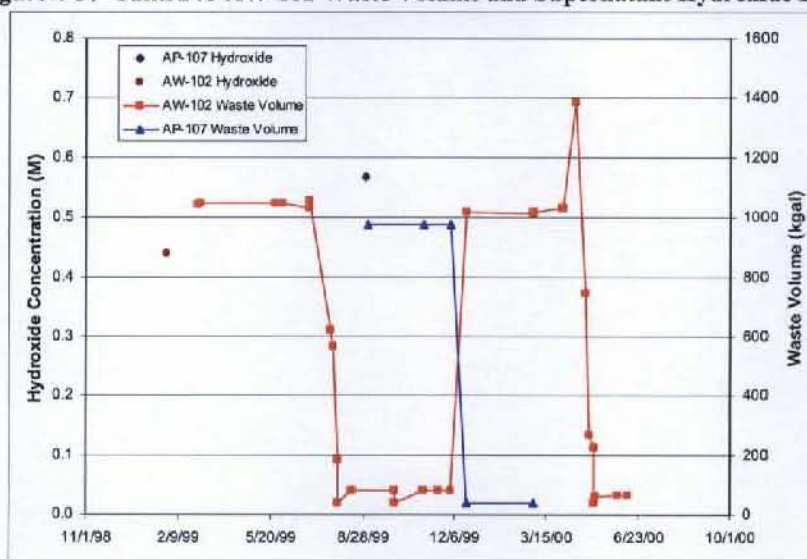
4.3.10.1 Tank 241-AW-101

The tank conditions and ventilation flow rates for the Tank 241-AW-101 evaluation presented in Section 4.3.9 after the flow control station was installed are applicable to the evaluation of the 241-AW Farm ventilation CO₂ concentrations and are used for that purpose.

4.3.10.2 Tank 241-AW-102

The Tank 241-AW-102 waste level is shown in Figure 4-37 (TWINS 2007). In December 1999 waste was transferred from Tank 241-AP-107 into Tank 241-AW-102. The Tank 241-AW-102 supernatant OH⁻ ion concentration after this transfer is essentially the Tank 241-AP-107 value prior to the transfer. The Tank 241-AW-102 supernatant OH⁻ ion concentration prior to the Tank 241-AP-107 waste transfer is over 0.4 M (TWINS 2007). The Tank 241-AP-107 supernatant OH⁻ ion concentration is almost 0.6 M as shown in Figure 4-37 and Table 4-9 (TWINS 2007).

Figure 4-37 Tank 241-AW-102 Waste Volume and Supernatant Hydroxide Data.



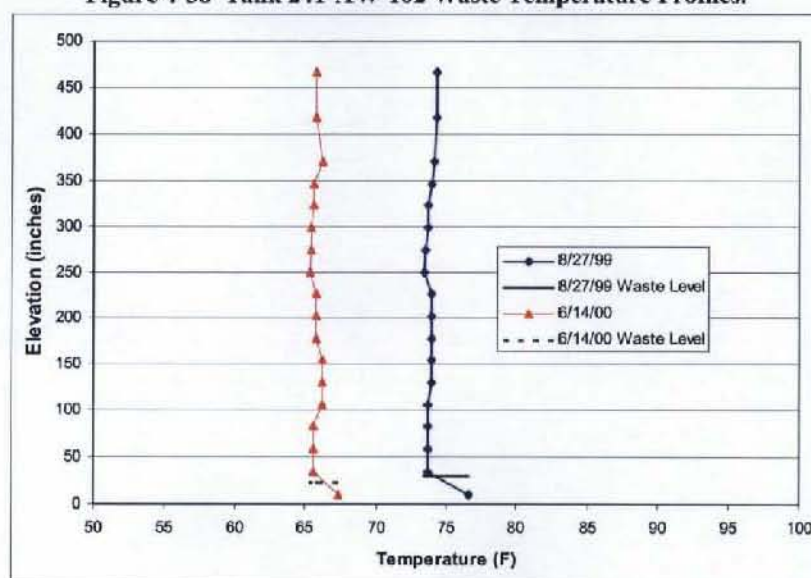
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Table 4-9 Tanks 241-AW-102 and 241-AP-107 Measured Hydroxide Concentrations.

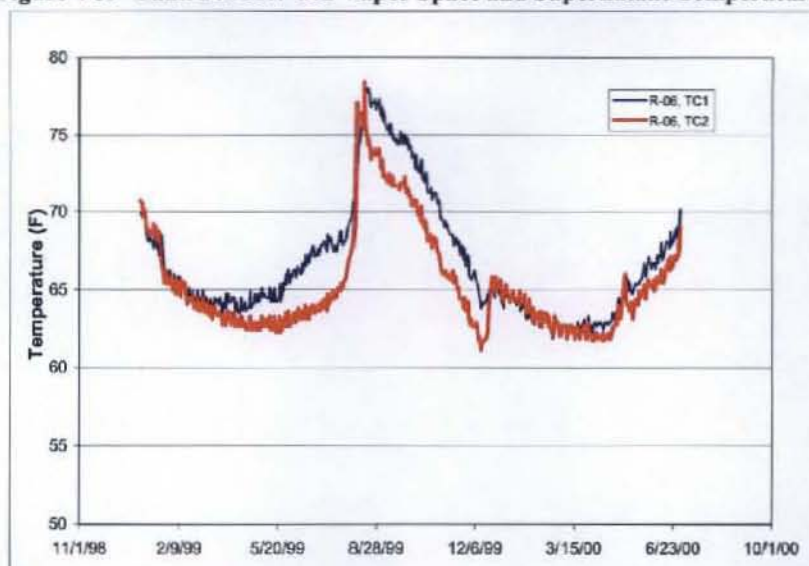
Tank Name	Aggregation Level	Sample Event Begin Date	Measured Value ($\mu\text{g/mL}$)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-AW-102	Grab Sample	1/27/99	7630	0.449	0.438	HNF-1665 Rev. 0	2AW-99-4C-T
241-AW-102	Grab Sample	1/27/99	7360	0.433		HNF-1665 Rev. 0	2AW-99-3C-T
241-AW-102	Grab Sample	1/27/99	7300	0.429		HNF-1665 Rev. 0	2AW-99-2C-T
241-AW-102	Grab Sample	1/27/99	7760	0.456		HNF-1665 Rev. 0	2AW-99-4C-T
241-AW-102	Grab Sample	1/27/99	7360	0.433		HNF-1665 Rev. 0	2AW-99-3C-T
241-AW-102	Grab Sample	1/27/99	7300	0.429		HNF-1665 Rev. 0	2AW-99-2C-T
241-AP-107	Grab Sample	8/30/99	9970	0.586	0.569	HNF-1689 Rev. 0	7AP-00-3C
241-AP-107	Grab Sample	8/30/99	9770	0.575		HNF-1689 Rev. 0	7AP-00-2C
241-AP-107	Grab Sample	8/30/99	9430	0.555		HNF-1689 Rev. 0	7AP-00-4C
241-AP-107	Grab Sample	8/30/99	9500	0.559		HNF-1689 Rev. 0	7AP-00-3C

The Tank 241-AW-102 waste temperature profiles and waste levels for August 27, 1999, and June 14, 2000, are shown in Figure 3-38 (TWINS 2007). The waste inventory was very small during the 241-AW Farm ventilation system CO₂ measurements shown in Figure 4-36. The tank heat load was also very low resulting in low tank temperatures (near ambient conditions) and small temperature differences between the supernatant and vapor space. The supernatant and vapor space temperatures are shown in Figure 4-39. The temperature difference is less than 1 °F during about 40% of the period of the CO₂ ventilation measurements. It is less the 0.1 °F about 20% of the time. A value of 1.0 °F was used for the evaluation to represent the whole period.

Figure 4-38 Tank 241-AW-102 Waste Temperature Profiles.



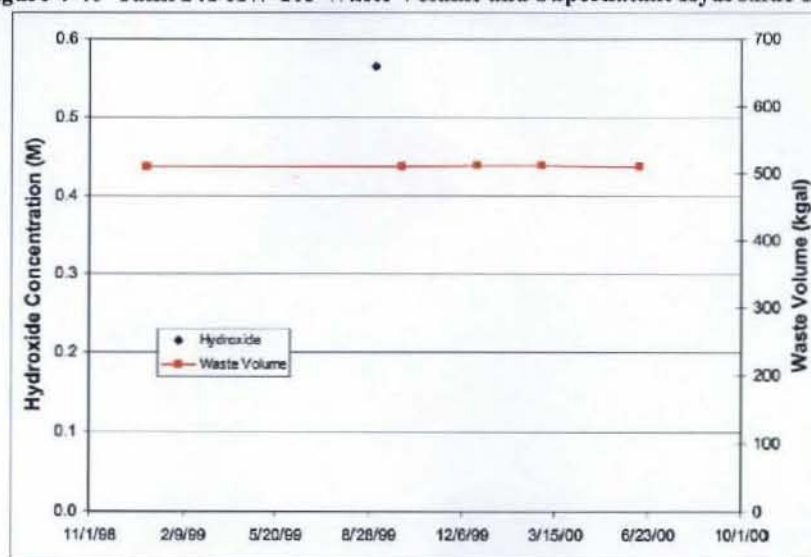
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Figure 4-39 Tank 241-AW-102 Vapor Space and Supernatant Temperatures.

The predicted Tank 241-AW-102 vapor space CO₂ concentration is 70 ppm.

4.3.10.3 Tank 241-AW-103

The Tank 241-AW-103 waste volume and supernatant OH⁻ ion concentration are shown in Figure 4-40 (TWINS 2007). The OH⁻ ion concentration data are shown in Table 4-10 (TWINS 2007). The supernatant OH⁻ ion concentration during the period of the 241-AW Farm ventilation system CO₂ measurements is 0.57 M.

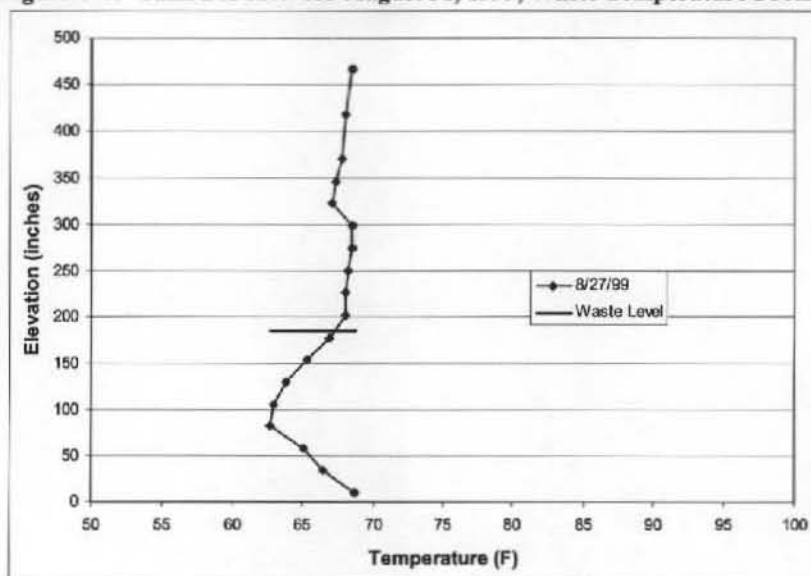
Figure 4-40 Tank 241-AW-103 Waste Volume and Supernatant Hydroxide Data.

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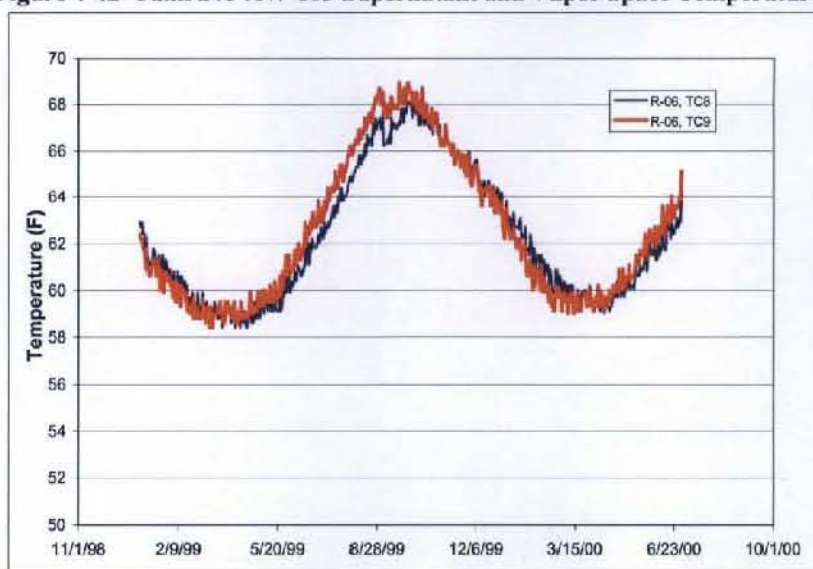
Table 4-10 Tank 241-AW-103 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Date	Measured Value (µg/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-AW-103	Core Composite	9/3/99	9850	0.579	0.566	HNF-1691 REV. 0	C265:CentLiquid 1
241-AW-103	Core Composite	9/3/99	9790	0.576		HNF-1691 REV. 0	C265:CentLiquid 2
241-AW-103	Core Composite	9/3/99	9990	0.588		HNF-1691 REV. 0	C265:CentLiquid 3
241-AW-103	Core Composite	9/8/99	9450	0.556		HNF-1691 REV. 0	C267:CentLiquid 1
241-AW-103	Core Composite	9/8/99	9310	0.548		HNF-1691 REV. 0	C267:CentLiquid 2
241-AW-103	Core Composite	9/8/99	9310	0.548		HNF-1691 REV. 0	C267:CentLiquid 3

The Tank 241-AW-103 waste temperature profile is shown in Figure 4-41 (TWINS 2007). The supernatant and vapor space temperatures are shown in Figure 4-42 (TWINS 2007). The supernatant temperature is low. The vapor space temperature difference is small and the vapor space temperature exceeds the supernatant temperature during the summer months. Since two of the three CO₂ concentration measurements shown in Figure 4-36 were measured in the summer months, a value of -0.1 °F was used for the evaluation.

Figure 4-41 Tank 241-AW-103 August 31, 1999, Waste Temperature Profile.

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Figure 4-42 Tank 241-AW-103 Supernatant and Vapor Space Temperatures.

The Tank 241-AW-103 vapor space CO₂ concentration predicted by the mechanistic depletion model was 239 ppm.

4.3.10.4 Tank 241-AW-104

The Tank 241-AW-104 waste volume and supernatant OH⁻ ion concentration are shown in Figure 4-43 (TWINS 2007). The measured OH⁻ ion data is shown in Table 4-11 (TWINS 2007). From the data, there is evidence of waste layering, with an upper dilute supernatant layer and layers of increasing OH⁻ ion concentration deeper in the tank. The OH⁻ ion concentration of the supernatant layer exposed to the tank vapor space is low, just under 0.07 M.

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Figure 4-43 Tank 241-AW-104 Waste Volume and Supernatant Hydroxide Data.

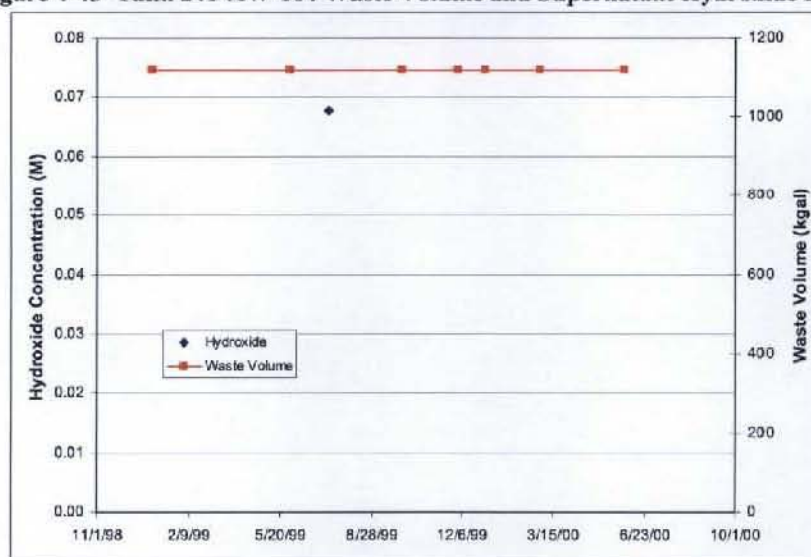


Table 4-11 Tank 241-AW-104 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Event Begin Date	Measured Value (µg/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-AW-104	Grab Sample	7/13/99	1130	0.066	0.068	HNF-1677, Rev.0	4AW-99-1
241-AW-104	Grab Sample	7/13/99	1120	0.066		HNF-1677, Rev.0	4AW-99-1
241-AW-104	Grab Sample	7/13/99	1140	0.067		HNF-1677, Rev.0	4AW-99-2
241-AW-104	Grab Sample	7/13/99	1180	0.069		HNF-1677, Rev.0	4AW-99-2
241-AW-104	Grab Sample	7/13/99	1130	0.066		HNF-1677, Rev.0	4AW-99-3
241-AW-104	Grab Sample	7/13/99	1210	0.071		HNF-1677, Rev.0	4AW-99-3
241-AW-104	Grab Sample	7/13/99	2380	0.140	N/A	HNF-1677, Rev.0	4AW-99-4
241-AW-104	Grab Sample	7/13/99	2380	0.140	N/A	HNF-1677, Rev.0	4AW-99-4
241-AW-104	Grab Sample	7/13/99	11700	0.688	N/A	HNF-1677, Rev.0	4AW-99-5
241-AW-104	Grab Sample	7/13/99	12100	0.712	N/A	HNF-1677, Rev.0	4AW-99-5

The waste temperature profile is shown in Figure 4-44 (TWINS 2007). The supernatant and vapor space temperatures are shown in Figure 4-45 (TWINS 2007). The vapor space temperature exceeds the supernatant temperature in the summer and early fall. However, for most of the year the supernatant temperature exceeds the vapor space temperature by 1 to 2 °F. A value of 1.5 °F is used for the evaluation.

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Figure 4-44 Tank 241-AW-104 August 27, 1999, Waste Temperature Profile.

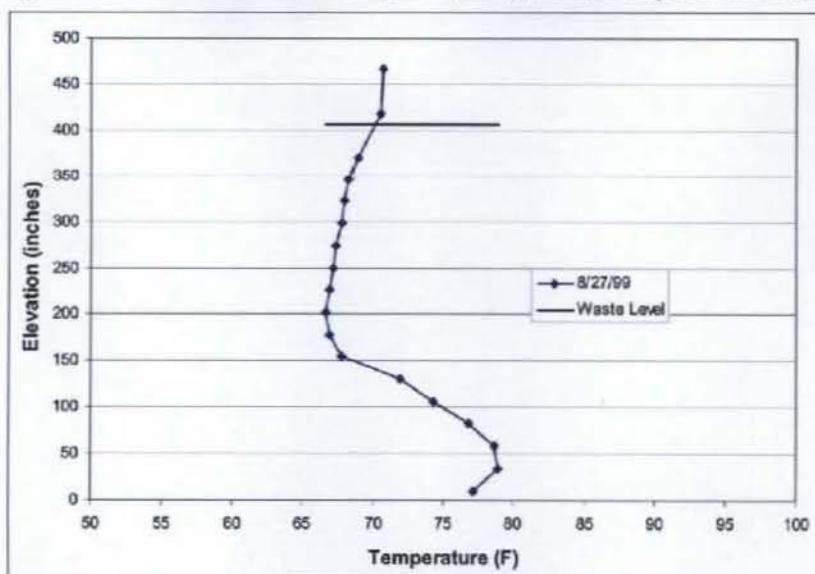
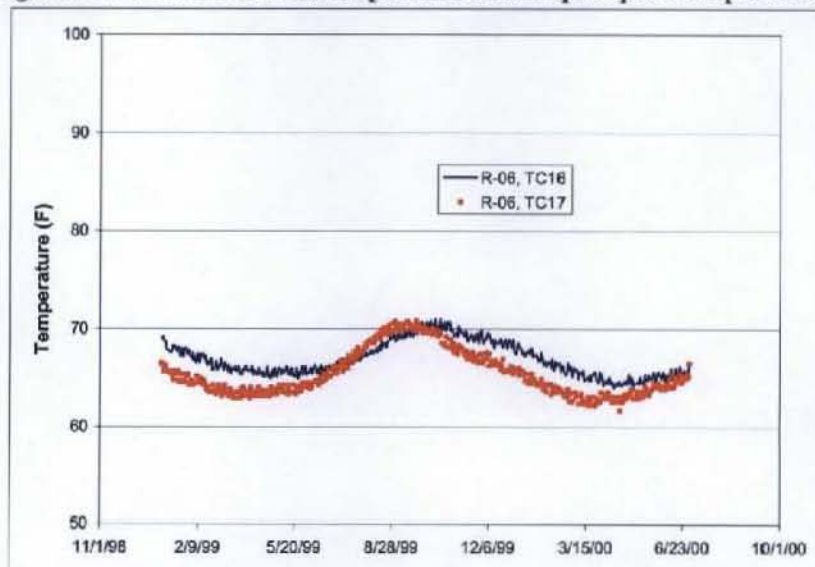


Figure 4-45 Tank 241-AW-104 Supernatant and Vapor Space Temperatures.



The predicted Tank 241-AW-104 vapor space CO₂ concentration is 140 ppm.

4.3.10.5 Tank 241-AW-105

The Tank 241-AW-105 waste volume and supernatant OH⁻ ion concentration are shown in Figure 4-46 (TWINS 2007). The supernatant OH⁻ data are given in Table 4-12 (TWINS 2007). The supernatant OH⁻ ion concentration is 0.25 M.

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Figure 4-46 Tank 241-AW-105 Waste Volume and Supernatant Hydroxide Data.

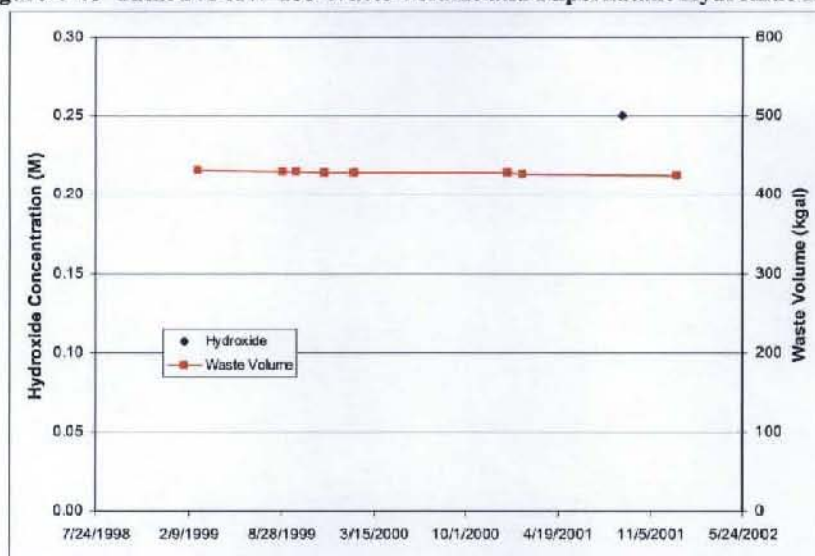
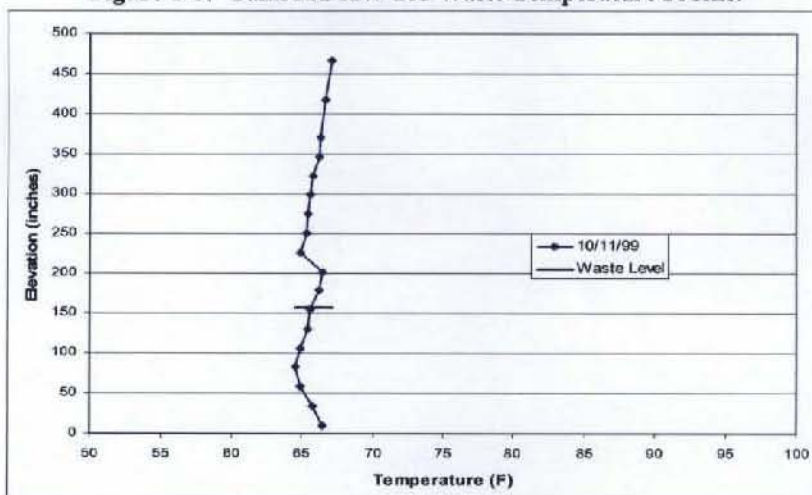


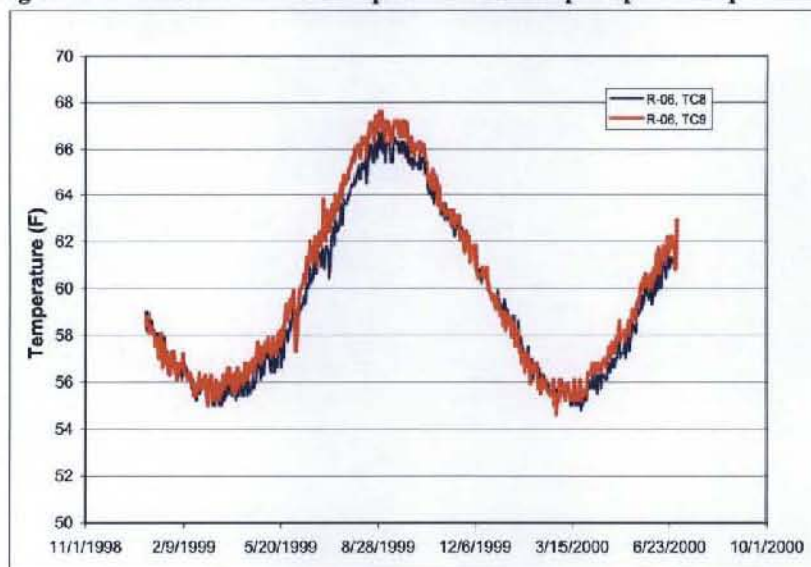
Table 4-12 Tank 241-AW-105 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Event Begin Date	Measured Value (µg/mL)	Molarity	Document Location	Sample Event Name	Segment Name
241-AW-105	Drainable Liquid	9/3/01	4290	0.25	FH-0106496	Core 295	1

Figure 4-47 Tank 241-AW-105 Waste Temperature Profile.



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Figure 4-48 Tank 241-AW-105 Supernatant and Vapor Space Temperatures.

The Tank 241-AW-105 waste temperature profile is shown in Figure 4-47 (TWINS 2007). The supernatant and vapor space temperatures are shown in Figure 4-48 (TWINS 2007). The supernatant temperature is low and the supernatant/vapor space temperature difference is small. For much of the year the vapor space temperature exceeds the supernatant temperature. A temperature difference of -0.1°F was used for the evaluation.

The Tank 241-AW-105 vapor space CO_2 concentration predicted by the mechanistic depletion model is 239 ppm.

4.3.10.6 Tank 241-AW-106

The Tank 241-AW-106 waste volume and supernatant OH^- ion concentration are shown in Figure 4-49 (TWINS 2007). The OH^- ion data are given in Table 4-13 (TWINS 2007). Tank 241-AW-102 waste was concentrated at 242-A Evaporator and transferred into Tank 241-AW-106 before the June 14, 2000, 241-AW Farm ventilation system CO_2 measurement shown in Figure 4-36. Table 4-9 shows that the Tank 241-AW-102 supernatant OH^- ion concentration before waste volume reduction was near the Tank 241-AW-106 supernatant OH^- ion concentration shown in Table 4-13. The supernatant OH^- ion concentration would be expected to be greater than 0.6 M after accounting for waste evaporation. A OH^- ion concentration of 0.6 M is used in the evaluation.

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Figure 4-49 Tank 241-AW-106 Waste Volume and Supernatant Hydroxide Data.

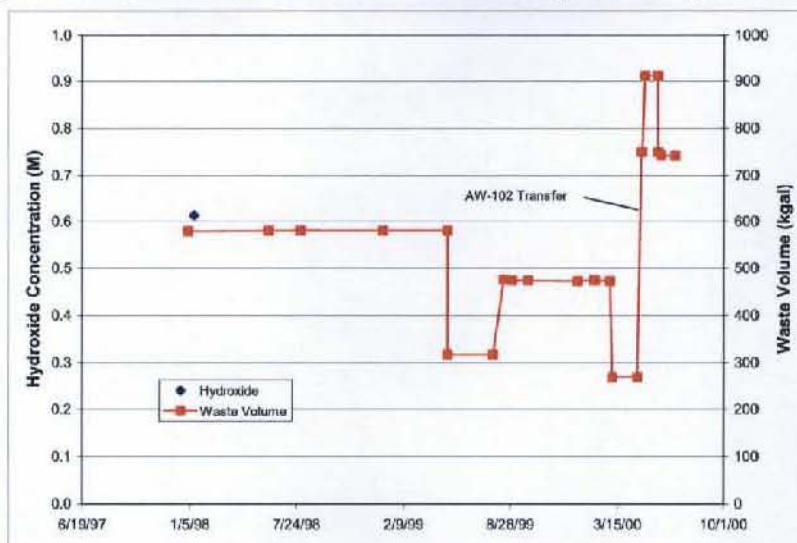
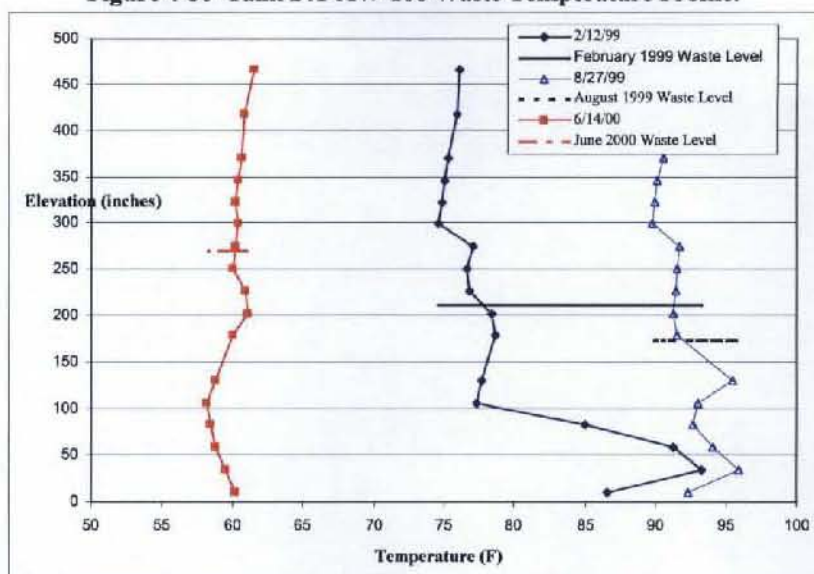


Table 4-13 Tank 241-AW-106 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Event Begin Date	Measured Value (µg/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-AW-106	Grab Sample	1/12/98	8690	0.511	0.576	HNF-SD-WM-DP-303, Rev. 0	6AW-97-4
241-AW-106	Grab Sample	1/12/98	9990	0.588		HNF-SD-WM-DP-303, Rev. 0	6AW-97-4
241-AW-106	Grab Sample	1/12/98	10400	0.612		HNF-SD-WM-DP-303, Rev. 0	6AW-97-5
241-AW-106	Grab Sample	1/12/98	10200	0.600		HNF-SD-WM-DP-303, Rev. 0	6AW-97-5
241-AW-106	Grab Sample	1/12/98	9710	0.571		HNF-SD-WM-DP-303, Rev. 0	6AW-97-6
241-AW-106	Grab Sample	1/12/98	9780	0.575		HNF-SD-WM-DP-303, Rev. 0	6AW-97-6

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Figure 4-50 Tank 241-AW-106 Waste Temperature Profile.

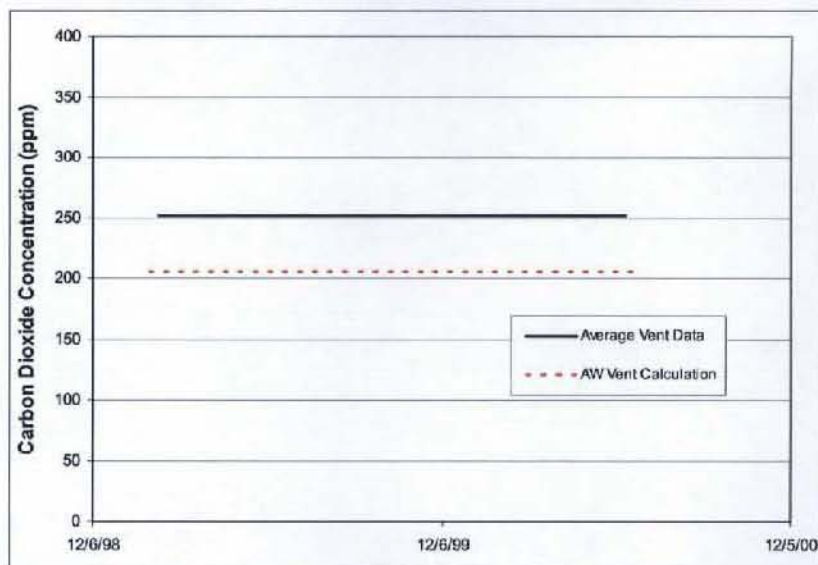
The waste temperature profiles for the three 241-AW Farm ventilation system CO₂ measurement dates shown in Figure 4-36 are shown in Figure 4-50 (TWINS 2007). The temperature difference between the supernatant and vapor space is small. A value of 0.1 °F is used for the evaluation.

The vapor space CO₂ concentration predicted by the mechanistic depletion model is 109 ppm.

4.3.10.7 241-AW Farm Ventilation System Results

The predicted 241-AW Farm tank vapor space CO₂ concentrations discussed in the previous sections are averaged using the Table 4-7 tank ventilation flow rates as weighting factors. The predicted and measured ventilation CO₂ concentration are shown in Figure 4-51. There is good agreement between the predicted and measured values. This demonstrates that the vapor space CO₂ concentrations for all the 241-AW Farm tanks are well predicted by the mechanistic depletion model.

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Figure 4-51 241-AW Farm Predicted and Measured Ventilation CO₂ Concentration.

4.3.11 Tank 241-AN-101

The Tank 241-AN-101 vapor space CO₂ data are shown in Figure 4-52 (TWINS 2007). The average CO₂ concentrations in March and April 1998 are near 50 ppm. The average CO₂ concentration starting in June 1998 is much higher, 290 ppm. An evaluation is performed for the vapor space CO₂ for both measurement periods.

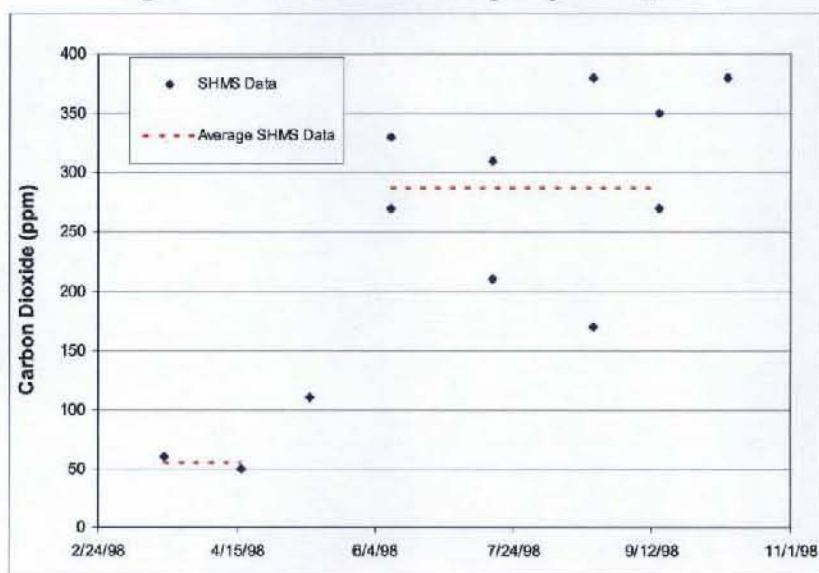
The waste volume and supernatant OH⁻ ion concentration are shown in Figure 4-53 (TWINS 2007). The OH⁻ ion data are given in Table 4-15 (TWINS 2007). From the data, there is evidence of waste layering, with an upper dilute supernatant layer and layers of increasing OH⁻ ion concentration deeper in the tank. The OH⁻ ion concentration of the supernatant layer exposed to the tank vapor space during the measurement period shown in Figure 4-52 is 0.38 M. The Tank 241-AN-101 waste volume is small, only about 160 in. of waste.

Table 4-14 summarizes the individual tank ventilation flow rates for the 241-AN Farm. The 241-AN Farm tanks have individual flow control stations, which maintain constant inlet filtered flow rates. The flow control station configurations are shown in Table 4-14 with the associated installation Engineering Change Notice (ECN) number and date. The estimated average total 241-AN Farm ventilation flow is near 764 cfm, RPP-7171. The difference between the total flow rate and the total flow control station flow rates is the unfiltered in-leakage. The lower portion of Table 4-14 gives the estimated tank total flow rates. The total in-leakage flow is proportioned equally to the individual tanks.

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Table 4-14 241-AN Farm Tank Ventilation Flow Rates.

ECN Number	ECN Date	Tank Flow Control Station Ventilation Flow (cfm)							Total Flow Control Station Flow (cfm)	Average Total Flow (cfm)
		AN101	AN102	AN103	AN104	AN105	AN106	AN107		
710248	5/6/1999	60	60	100	100	100	60	60	540	764
661166	8/31/2000	60	60	60	60	60	60	60	420	764
666412	5/7/2001	60	60	60	60	60	60	90	450	764
666600	6/27/2001	60	90	60	60	60	60	60	450	764
Estimated Total Tank Ventilation Flow (cfm)										
	ECN Date	AN101	AN102	AN103	AN104	AN105	AN106	AN107		
	5/6/1999	92	92	132	132	132	92	92		
	8/31/2000	109	109	109	109	109	109	109		
	5/7/2001	105	105	105	105	105	105	135		
	6/27/2001	105	135	105	105	105	105	105		

Figure 4-52 Tank 241-AN-101 Vapor Space CO₂ Data.

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Figure 4-53 Tank 241-AN-101 Waste Volume and Supernatant Hydroxide Data.

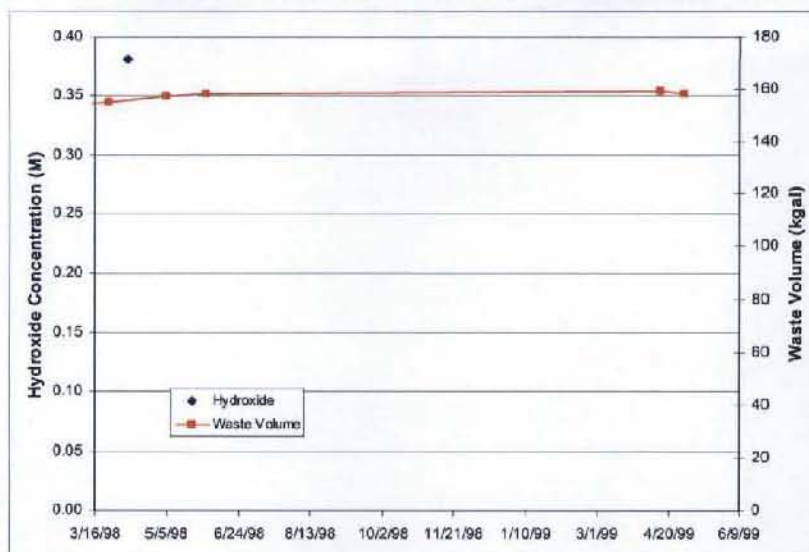


Table 4-15 Tank 241-AN-101 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Event Begin Date	Measured Value (µg/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-AN-101	Grab Sample	4/8/98	6580	0.387	0.381	HNF-1640 Rev. 0	1AN-98-1
241-AN-101	Grab Sample	4/8/98	6370	0.375		HNF-1640 Rev. 0	1AN-98-1
241-AN-101	Grab Sample	4/8/98	26600	1.565		HNF-1640 Rev. 0	1AN-98-2
241-AN-101	Grab Sample	4/8/98	26800	1.576		HNF-1640 Rev. 0	1AN-98-2
241-AN-101	Grab Sample	4/8/98	34100	2.006		HNF-1640 Rev. 0	1AN-98-3
241-AN-101	Grab Sample	4/8/98	32100	1.888		HNF-1640 Rev. 0	1AN-98-3

The Tank 241-AN-101 June 9, 1998, waste temperature profile is shown in Figure 4-54 (TWINS 2007). The vapor space and supernatant temperatures are shown in Figure 4-55 (TWINS 2007). The supernatant/vapor space temperature difference is also shown in Figure 4-55. During the period that the vapor space CO₂ data was near 50 ppm, the temperature difference was small but positive (supernatant temperature greater than the vapor space temperature). A value of 0.04 °F was used for this period. During the period corresponding to the summer and early fall, where the vapor space CO₂ concentrations are much higher, the supernatant/vapor space temperature difference is small and negative (vapor space temperature greater than supernatant). A value of -0.01 °F was used for the evaluation. During this period the mass transfer coefficient is smaller since the mass transfer coefficient is a function of the temperature difference.

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Figure 4-54 Tank 241-AN-101 Waste Temperature Profile.

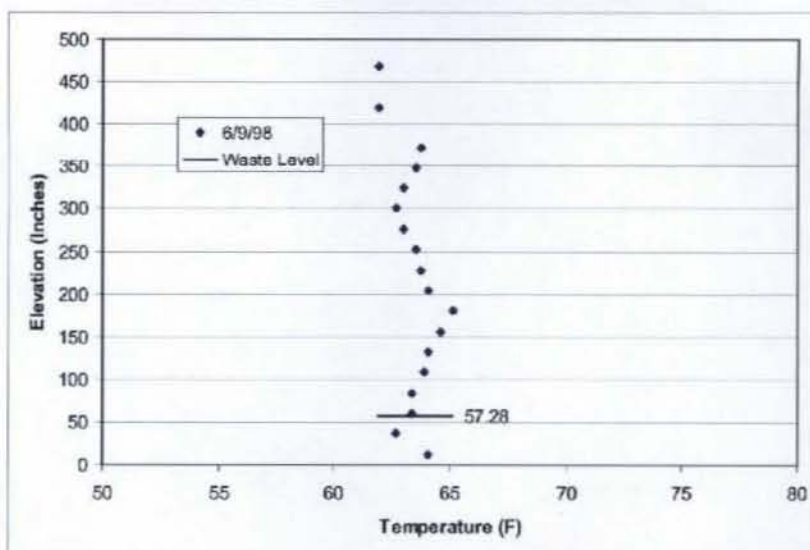
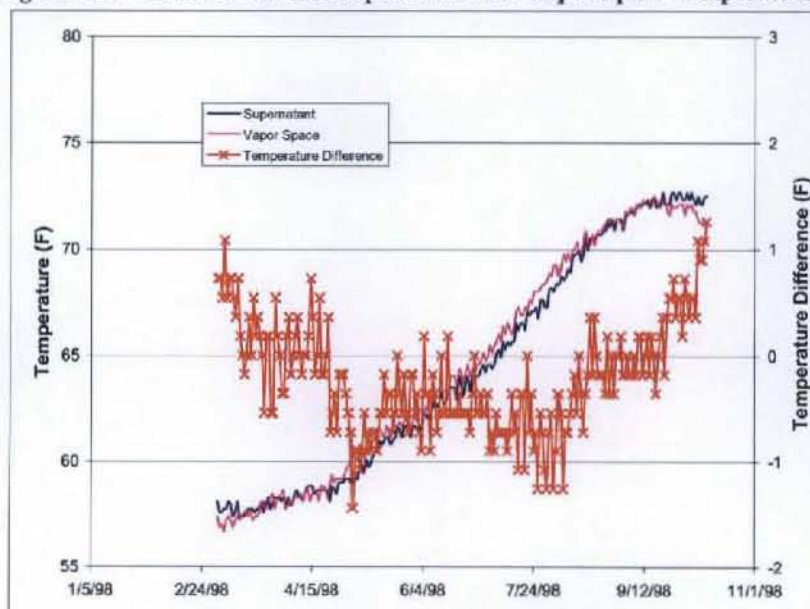
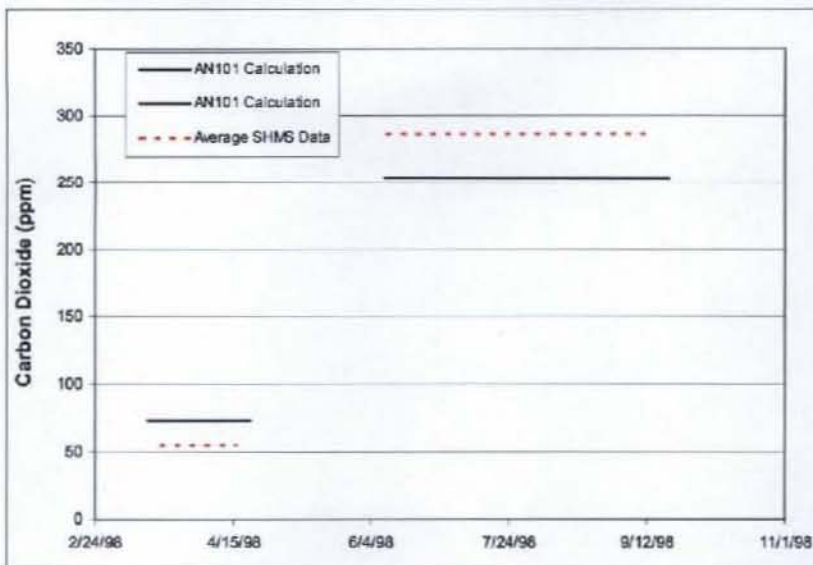


Figure 4-55 Tank 241-AN-101 Supernatant and Vapor Space Temperatures.



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Figure 4-56 Tank 241-AN-101 Predicted and Measured Vapor Space CO₂ Concentrations.

The mechanistic depletion model is used to predict the vapor space CO₂ concentration for the two periods discussed above. The results of the analyses are compared with the average measured data in Figure 4-56. During the first period the CO₂ mass transfer is only limited by the ventilation air supply. Consequently, the vapor space CO₂ concentration is low. During the second period the CO₂ mass transfer rate is limited by the vapor side mass transfer. The vapor space CO₂ concentration is much larger during this period. There is good agreement with the predicted and measured values for the periods.

4.3.12 Tank 241-AN-103

The Tank 241-AN-103 vapor space CO₂ data are shown in Figure 4-57 (TWINS 2007). The average value is 355 ppm. The waste volume and supernatant OH⁻ ion concentrations are shown in Figure 4-58 (TWINS 2007). The supernatant OH⁻ ion concentration is quite high, greater than 5.0 M, as shown in Table 4-16 (TWINS 2007).

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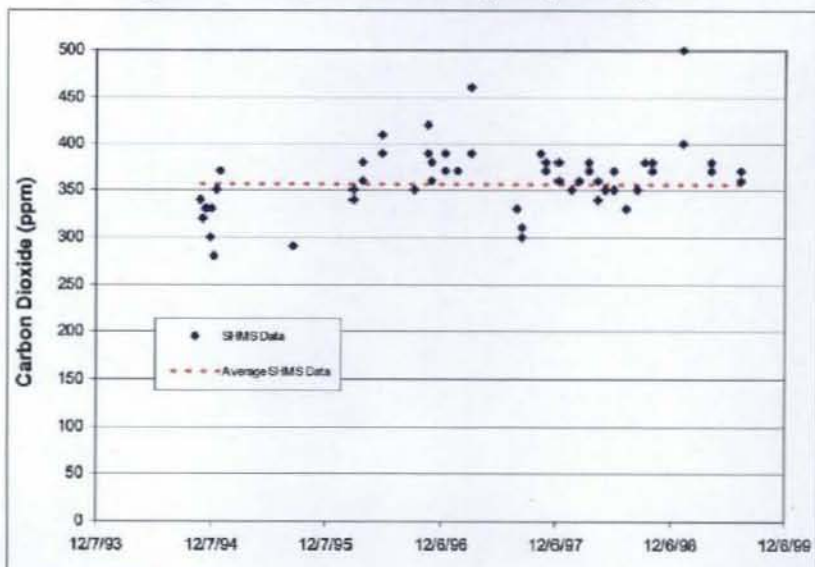
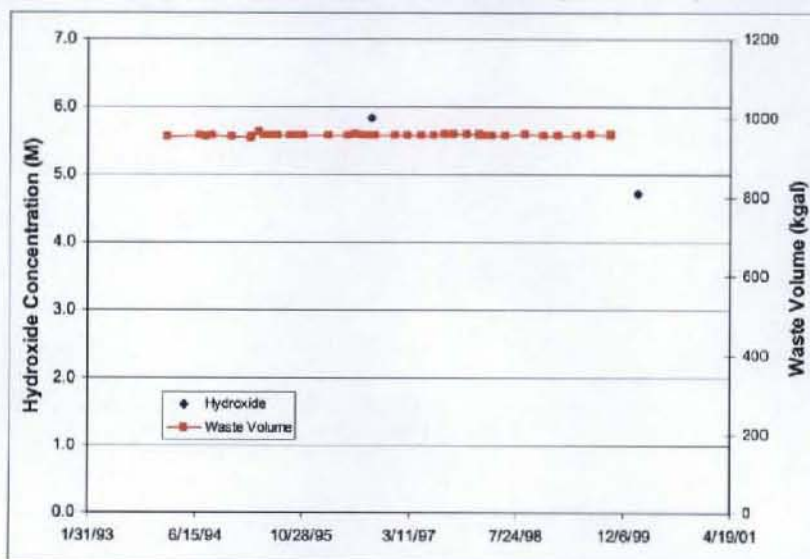
Figure 4-57 Tank 241-AN-103 Vapor Space CO₂ Data.

Figure 4-58 Tank 241-AN-103 Waste Volume and Supernatant Hydroxide Data.



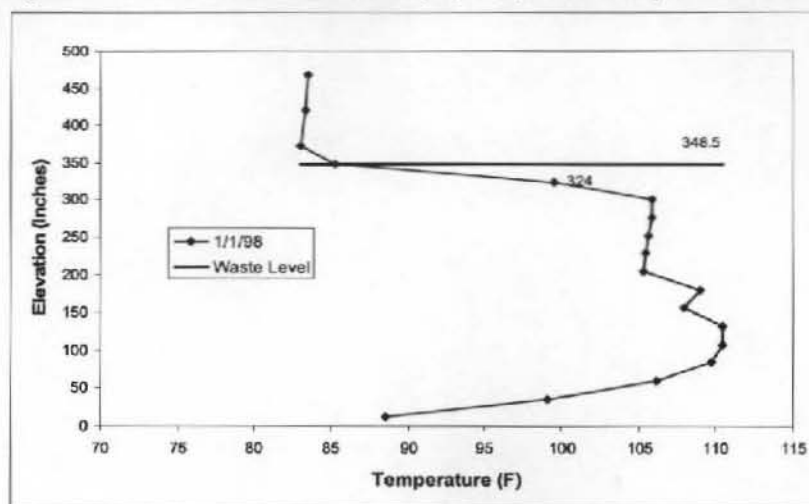
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Table 4-16 Tank 241-AN-103 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Event Begin Date	Measured Value ($\mu\text{g/mL}$)	Molarity	Average Value (M)	Document Location	Sampling Event Name	Segment
241-AN-103	DL Core Composite	9/13/96	104000	6.11	5.840	WMH-9859035	166	
241-AN-103	DL Core Composite	9/13/96	100000	5.88		WMH-9859035	166	
241-AN-103	DL Core Composite	9/13/96	91700	5.39		WMH-9859035	166	
241-AN-103	DL Core Composite	9/13/96	99700	5.86		HNF-SD-WM-DP-223, Rev. 0	166	
241-AN-103	DL Core Composite	9/13/96	95600	5.62		WMH-9859035	166	
241-AN-103	DL Core Composite	9/13/96	108000	6.35		WMH-9859035	166	
241-AN-103	DL Core Composite	9/13/96	99000	5.82		WMH-9859035	166	
241-AN-103	DL Core Composite	9/13/96	96700	5.69		HNF-SD-WM-DP-223, Rev. 0	166	
241-AN-103	Segment Solids	2/9/00	67300	3.96	3.96	FH-0201779	274	2
241-AN-103	Segment Solids	2/9/00	67300	3.96		FH-0201779	274	2

The January 1, 1998, waste temperature profile is shown in Figure 4-59. There is a steep temperature gradient near the waste surface. This is the result of a surface crust. The mechanistic depletion model assumes molecular diffusion through the crust region. The crust thickness based upon the waste temperature profile is at least 25 in. The same empirical porosity value for the crust which was determined for Tank 241-SY-101, Section 4.3.5, is used for the Tank 241-AN-103 surface crusts.

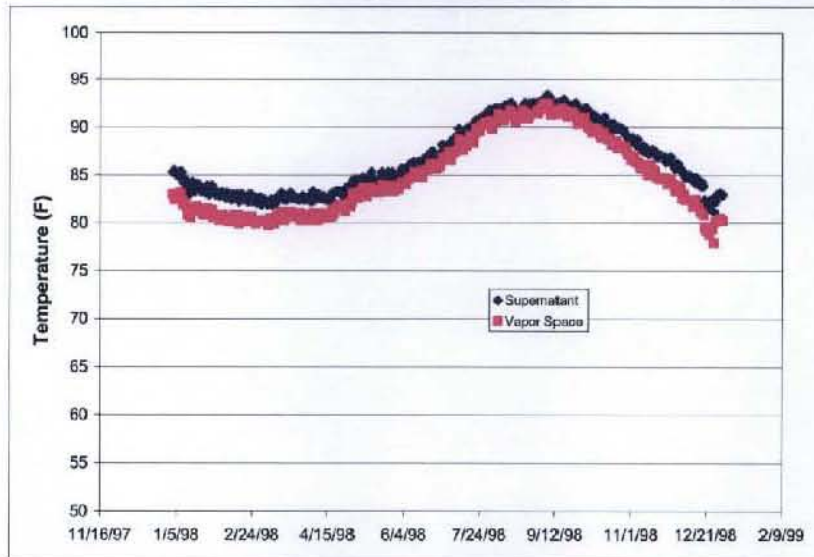
Figure 4-59 Tank 241-AN-103 January 1, 1998, Waste Temperature Profile.



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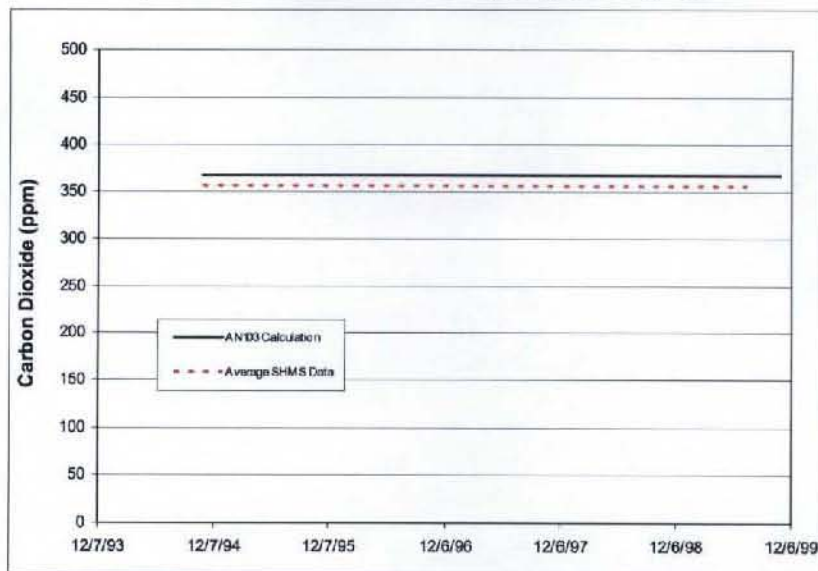
The supernatant and vapor space temperatures are shown in Figure 4-60 (TWINS 2007). The average supernatant and vapor space temperature difference is 1.8 °F.

Figure 4-60 Tank 241-AN-103 Supernatant and Vapor Space Temperatures.



The mechanistic depletion model is used to predict the vapor space CO₂ concentration for Tank 241-AN-103. The CO₂ mass transfer for this tank is limited by the mass transfer through the surface crust. The predicted vapor space CO₂ concentration is compared to the average measured data in Figure 4-61. There is good agreement with the data.

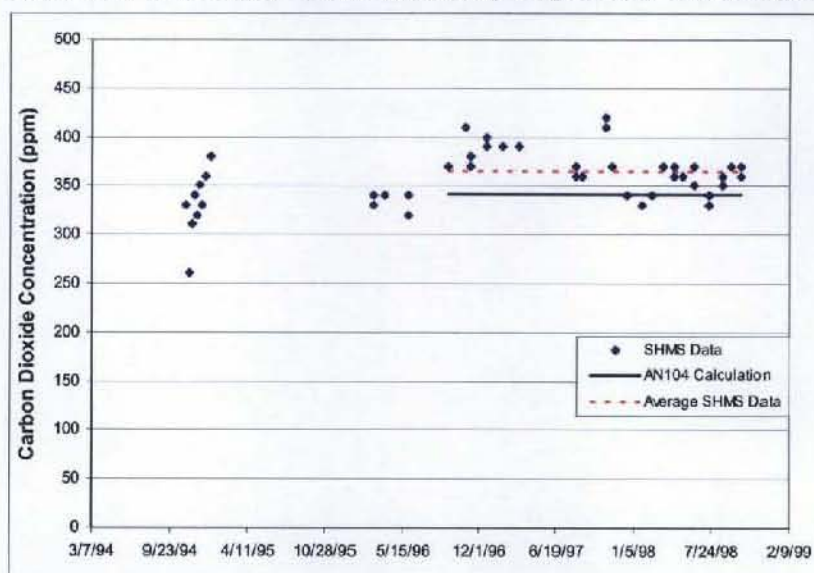
Figure 4-61 Tank 241-AN-103 Vapor Space CO₂ Data.



4.3.13 Tank 241-AN-104

Tank 241-AN-104 supernatant OH^- ion depletion is evaluated in Section 3.2.1. The analysis is used to determine the vapor space CO_2 concentration. The vapor space CO_2 data are shown in Figure 4-62 (TWINS 2007). Tank 241-AN-104 has a surface crust. This crust limits the OH^- ion mass transfer on the liquid side, which greatly reduces the CO_2 absorption rate. As a result, the vapor space CO_2 concentration is high. The same empirical value for the crust porosity which was determined for Tank 241-SY-101, Section 4.3.5, is used for the Tank 241-AN-103 surface crusts

Figure 4-62 Tank 241-AN-104 Measured Vapor Space CO_2 Concentrations.



The predicted vapor space CO_2 concentration based upon the mechanistic depletion model analyses presented in Section 3.2.1 is shown in Figure 4-62. The predicted vapor space CO_2 concentration is 342 ppm. This is in excellent agreement with the data.

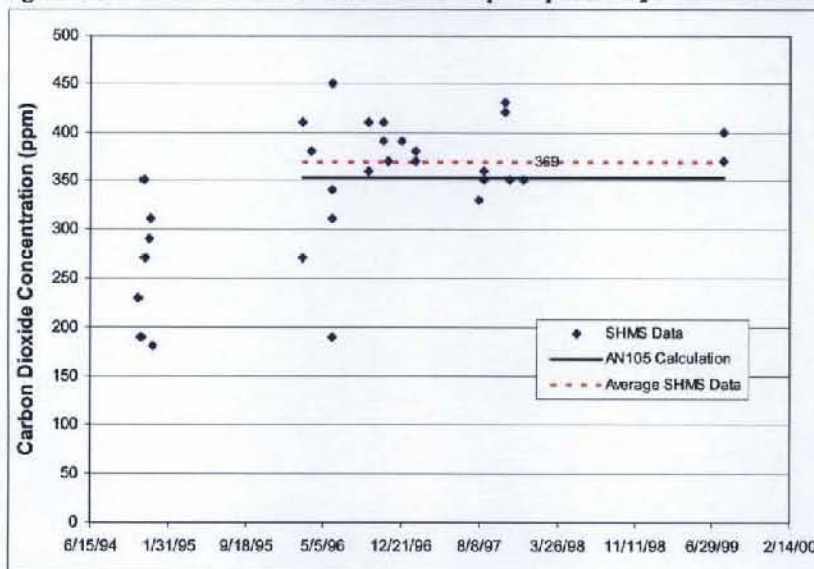
4.3.14 Tank 241-AN-105

Tank 241-AN-105 supernatant OH^- ion depletion is evaluated in Section 3.2.2. The analysis is used to determine the vapor space CO_2 concentration. The vapor space CO_2 data are shown in Figure 4-63 (TWINS 2007). Tank 241-AN-105 has a surface crust. This crust limits the OH^- ion mass transfer on the liquid side, which greatly reduces the CO_2 absorption rate. As a result, the vapor space CO_2 concentration is high. The same empirical porosity value for the crust which was determined for Tank 241-SY-101, Section 4.3.5, is used for the Tank 241-AN-103 surface crusts.

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The predicted vapor space CO₂ concentration based upon the mechanistic depletion model analyses presented in Section 3.2.2 is shown in Figure 4-63. The predicted vapor space CO₂ concentration is 350 ppm. There is good agreement with the predicted and measured values.

Figure 4-63 Tank 241-AN-105 Measured Vapor Space CO₂ Concentrations.

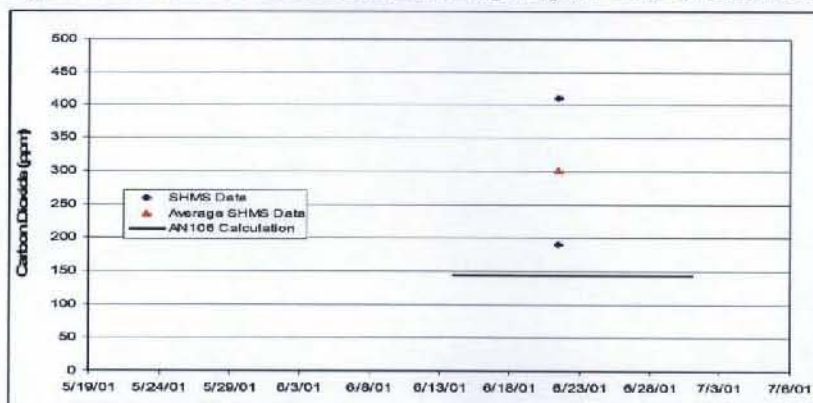


4.3.15 Tank 241-AN-106

The Tank 241-AN-106 measured vapor space CO₂ concentration for June 21, 2001, are shown in Figure 4-64 (TWINS 2007). Only two measurements are available. The average vapor space CO₂ concentration is near 300 ppm.

The Tank 241-AN-106 measured supernatant OH⁻ ion concentrations are shown in Figure 4-65 and Table 4-17 (TWINS 2007). The measured average OH⁻ ion concentration is 0.21 M. The waste volume, also shown in Figure 4-65, is very small.

Figure 4-64 Tank 241-AN-106 Measured Vapor Space CO₂ Concentrations.



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Figure 4-65 Tank 241-AN-106 Waste Volume and Supernatant Hydroxide Data.

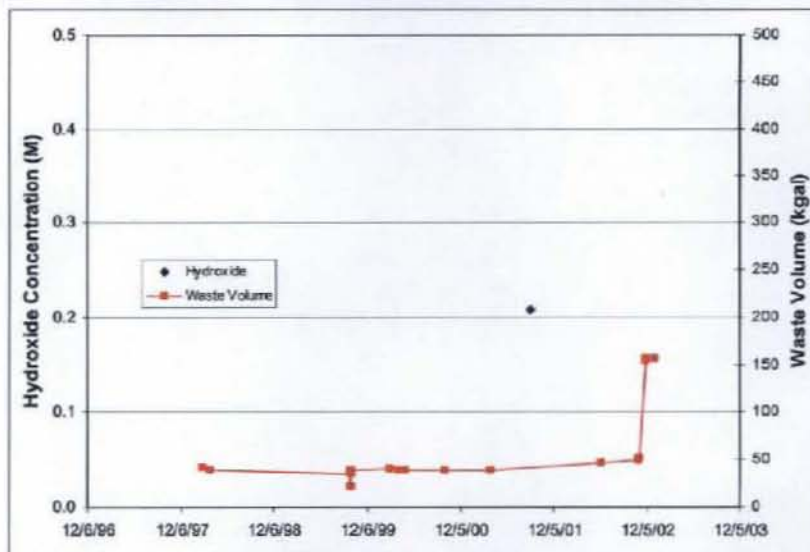


Table 4-17 Tank 241-AN-106 Measured Hydroxide Concentrations.

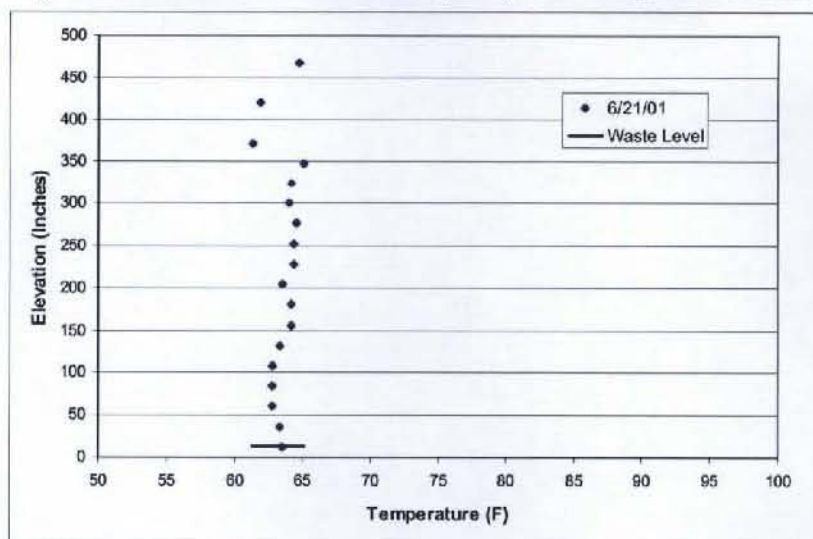
Tank Name	Aggregation Level	Sample Event Begin Date	Measured Value (µg/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-AN-106	Grab Sample	9/4/01	3620	0.213	0.207	FH-0106401	6AN-01-01
241-AN-106	Grab Sample	9/4/01	3310	0.195		FH-0106401	6AN-01-01
241-AN-106	Grab Sample	9/4/01	3690	0.217		FH-0106401	6AN-01-01
241-AN-106	Grab Sample	9/4/01	3470	0.204		FH-0106401	6AN-01-01

The Tank 241-AN-106 waste temperature profile is shown in Figure 4-66 (TWINS 2007). The waste level is very low, near 14 in. The supernatant temperature is less than 65 °F and the temperature difference between the supernatant and vapor space is very small. A value of 0.01 °F is used for the evaluation.

The vapor space CO₂ concentration predicted by the mechanistic depletion model is shown in Figure 4-64. There is agreement with the predicted vapor space CO₂ concentration and the minimum measured data point. The predicted vapor space CO₂ concentration is significantly lower than the average measured vapor space CO₂ concentration. The paucity of CO₂ presents a challenge in making comparison of the model result with the measured data. A value of 410 ppm could have been caused by sampling and/or analysis difficulties since the concentration is considered higher than that of nominal atmospheric air.

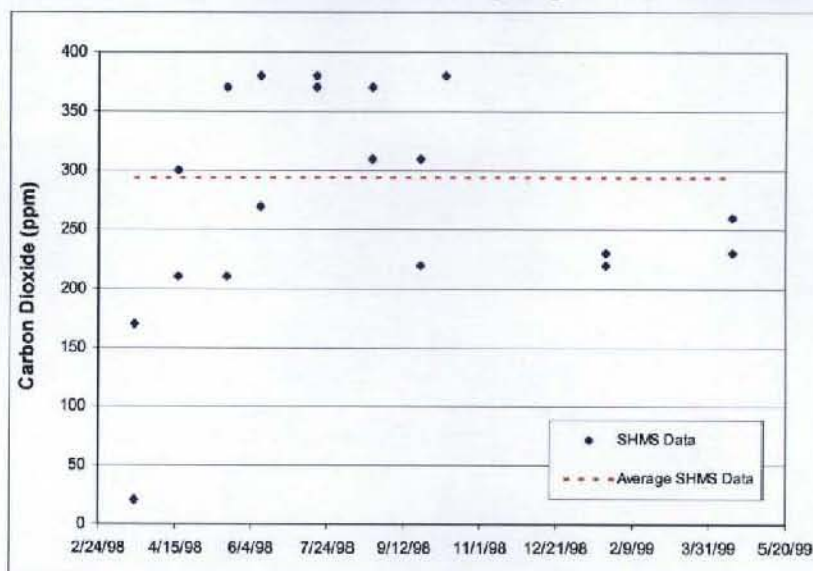
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Figure 4-66 Tank 241-AN-106 June 21, 2001, Waste Temperature Profile.



4.3.16 Tank 241-AN-107

The Tank 241-AN-107 measured vapor space CO₂ concentrations from March 1998 to April 1999 are shown in Figure 4-67 (TWINS 2007). The average measured value during this period is near 300 ppm.

Figure 4-67 Tank 241-AN-107 Measured Vapor Space CO₂ Concentration.

The measured supernatant OH⁻ ion concentration is shown in Figure 4-68 and Table 4-18 (TWINS 2007). The average of the measured data (0.0016 M) is used for the evaluation. The OH⁻ ion concentration is sufficiently low to cause carbonate buffering, reducing the CO₂ mass transfer rate.

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Figure 4-68 Tank 241-AN-107 Waste Volume and Measured Hydroxide Data.

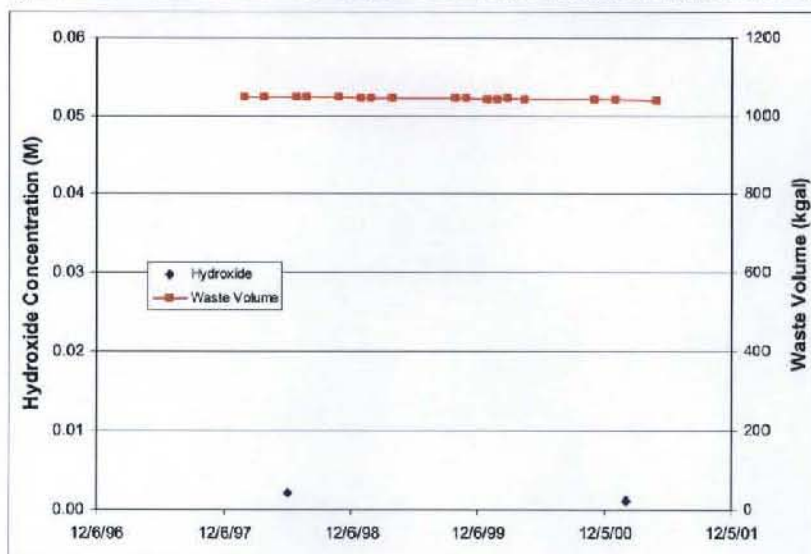
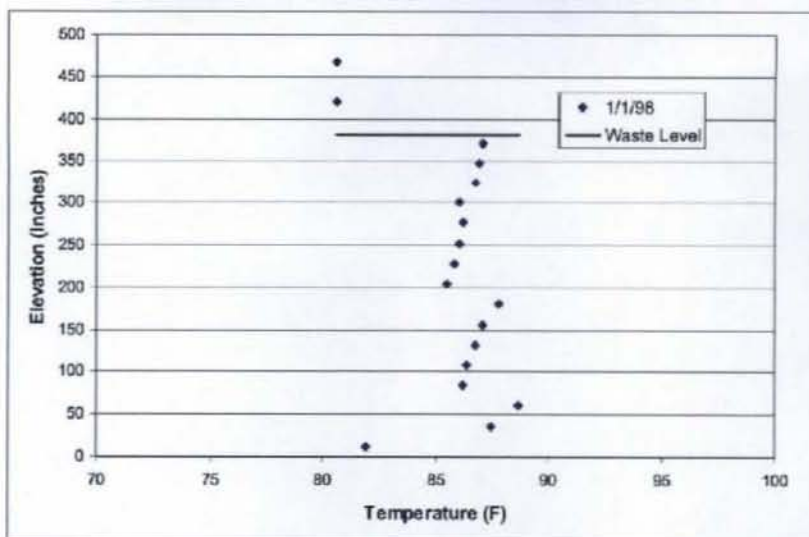
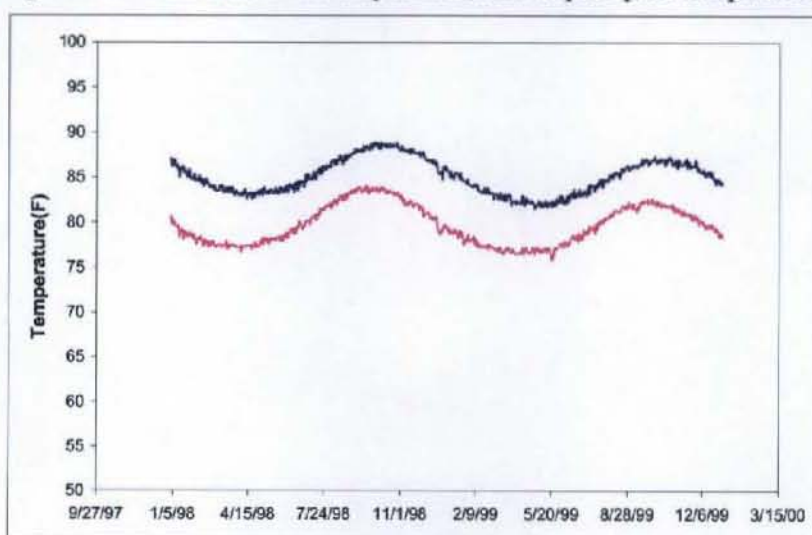


Table 4-18 Tank 241-AN-107 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Event Begin Date	Measured Value (pH)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-AN-107	Grab Sample	6/9/98	11.28	0.002	0.002	FH-0103281	7AN-98-38
241-AN-107	Grab Sample	6/9/98	11.3	0.002		FH-0103281	7AN-98-38
241-AN-107	Grab Sample	2/5/01	10.94	0.0009	0.0011	FH-0103281	7AN-01-01
241-AN-107	Grab Sample	2/5/01	10.88	0.0008		FH-0103281	7AN-01-06
241-AN-107	Grab Sample	2/5/01	11.2	0.0016		FH-0103281	7AN-01-11

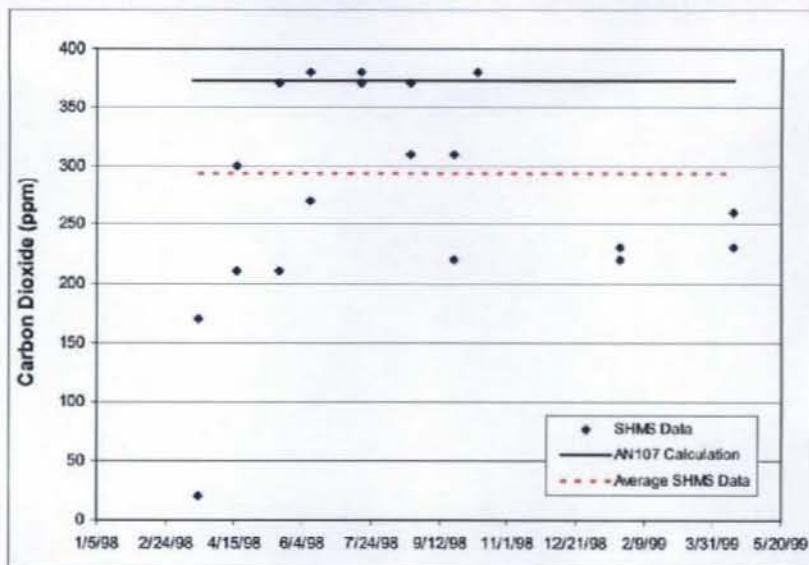
The Tank 241-AN-107 January 1, 1998, waste temperature profile is shown in Figure 4-69 (TWINS 2007). The supernatant and vapor space temperatures are shown in Figure 4-70 (TWINS 2007). The supernatant and vapor space temperature difference is approximately 5 °F.

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Figure 4-69 Tank 241-AN-107 Waste Temperature Profile.**Figure 4-70 Tank 241-AN-107 Supernatant and Vapor Space Temperature.**

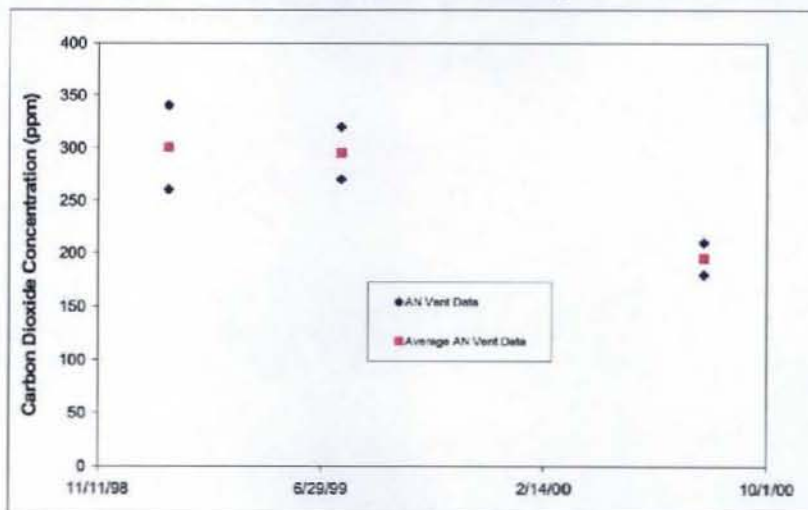
The mechanistic depletion model is used to predict the Tank 241-AN-107 vapor space CO₂ concentration. The predicted CO₂ concentration of 372 ppm is compared with the average measured value in Figure 4-71. The predicted vapor space CO₂ concentration is higher than the average measured data. However, both indicate high CO₂ concentrations which are primarily due to the low OH⁻ ion concentration, resulting in CO₃ buffering.

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Figure 4-71 Tank 241-AN-107 Predicted and Measured Vapor Space CO₂ Concentration.

4.3.17 241-AN Farm Ventilation System Carbon Dioxide Evaluation

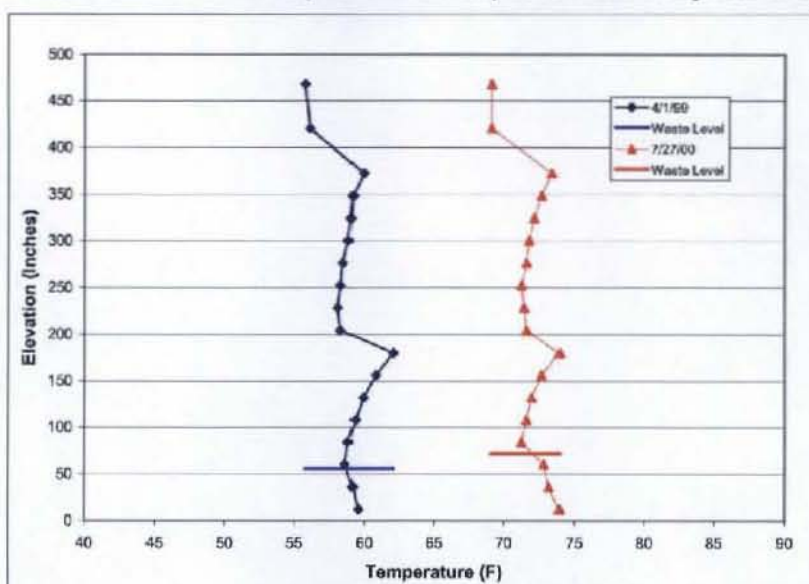
The 241-AN Farm ventilation system CO₂ concentration data are shown in Figure 4-72 (TWINS 2007). The ventilation air CO₂ concentrations are higher in 1999 compared to the July 2000 measurements. The mechanistic depletion model is used to predict the ventilation air CO₂ concentration for the two periods, January 1999 to July 1999, and July 2000. The vapor space CO₂ concentration for each individual tank is predicted. The ventilation air CO₂ concentration is then the flow weighted average of the individual tank vapor space CO₂ concentrations. The individual tank flow rates shown in Table 4-14 are used for the evaluation.

Figure 4-72 241-AN Farm Ventilation CO₂ Concentration.

4.3.17.1 Tank 241-AN-101

Figure 4-73 shows the Tank 241-AN-101 waste temperature profiles in April 1999 and July 2000 (TWINS 2007). The supernatant/vapor space temperature difference near the waste surface is very small in April 1999, less than 1 °F. This difference is larger on July 27, 2000, over 1 °F. The CO₂ evaluation performed in Section 4.3.11 is used for the earlier period shown in Figure 4-72. An additional mechanistic depletion model analysis is performed in the July 27, 2000, time frame using a supernatant/vapor space temperature difference of 1 °F. The supernatant OH⁻ ion concentration for July 2000 is assumed to be near the value shown in Figure 4-53.

Figure 4-73 Tank 241-AN-101 April 1999 and July 2000 Waste Temperature Profiles.

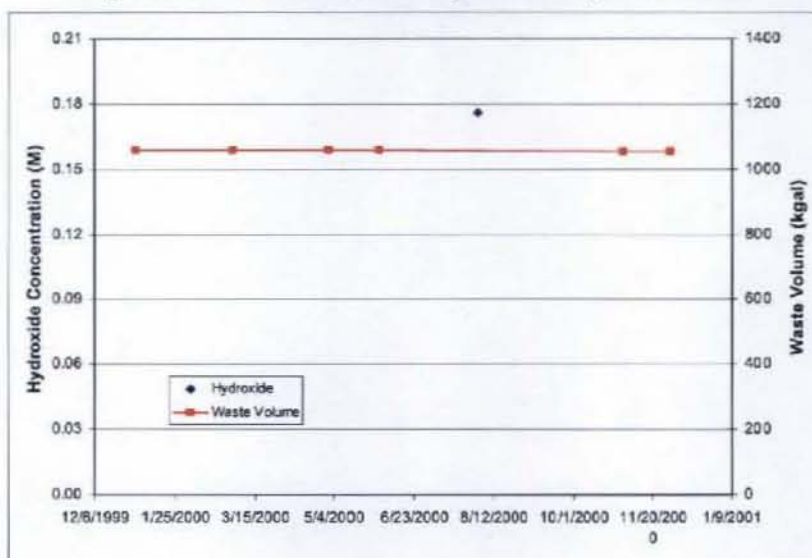


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4.3.17.2 Tank 241-AN-102

Figure 4-74 and Table 4-19 shows the Tank 241-AN-102 supernatant OH^- ion concentration (TWINS 2007). The OH^- ion concentration is near 0.18 M in August 2000.

Figure 4-74 Tank 241-AN-102 Supernatant Hydroxide Data.

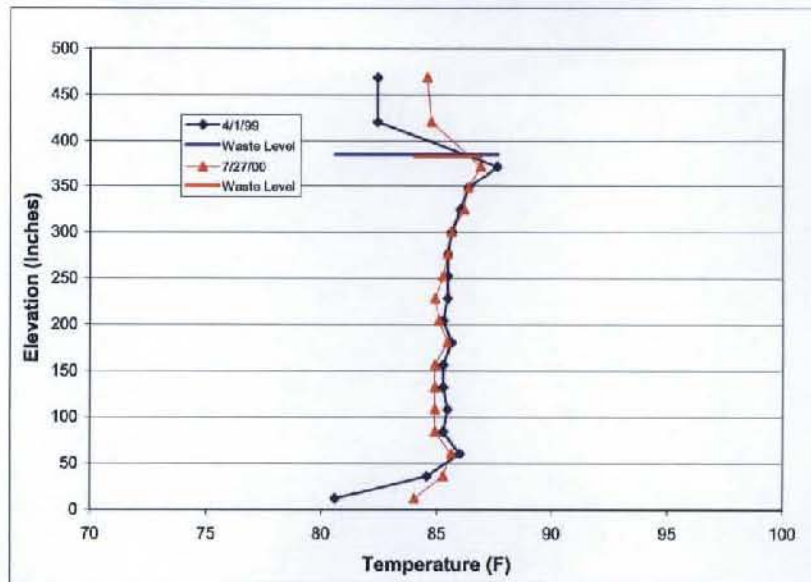


The Tank 241-AN-102 waste temperature profile is shown in Figure 4-75 (TWINS 2007). The supernatant temperature is approximately 85 °F with a supernatant/vapor space temperature difference that exceeds 2 °F. The supernatant/vapor space temperature difference for the April 1999 and July 27, 2000, periods shown in Figure 4-75 are essentially the same.

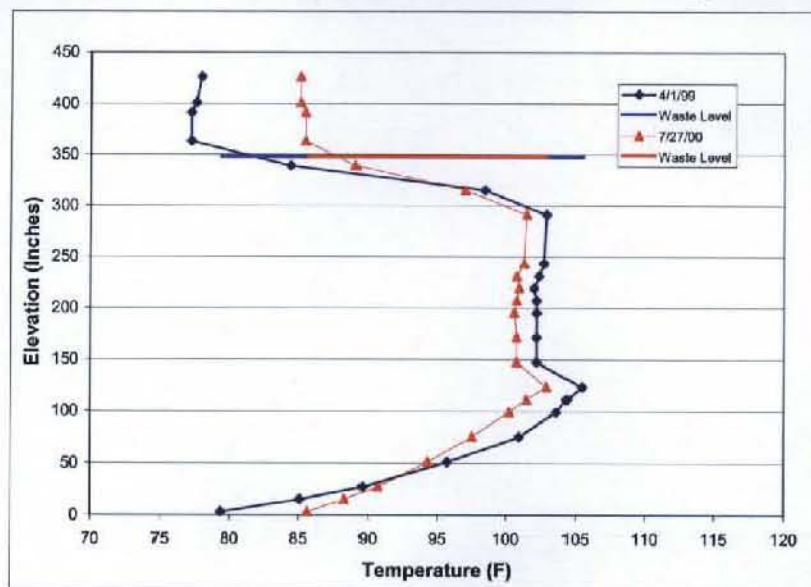
Table 4-19 Tank 241-AN-102 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Event Begin Date	Measured Value (pH)/ (µg/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-AN-102	Grab Sample	8/2/00	13.27	0.186	0.176	FH-0103058 Reissue	2AN-00-9
241-AN-102	Grab Sample	8/2/00	13.22	0.166		FH-0103058 Reissue	2AN-00-9

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Figure 4-75 Tank 241-AN-102 Waste Temperature Profile.**4.3.17.3 Tank 241-AN-103**

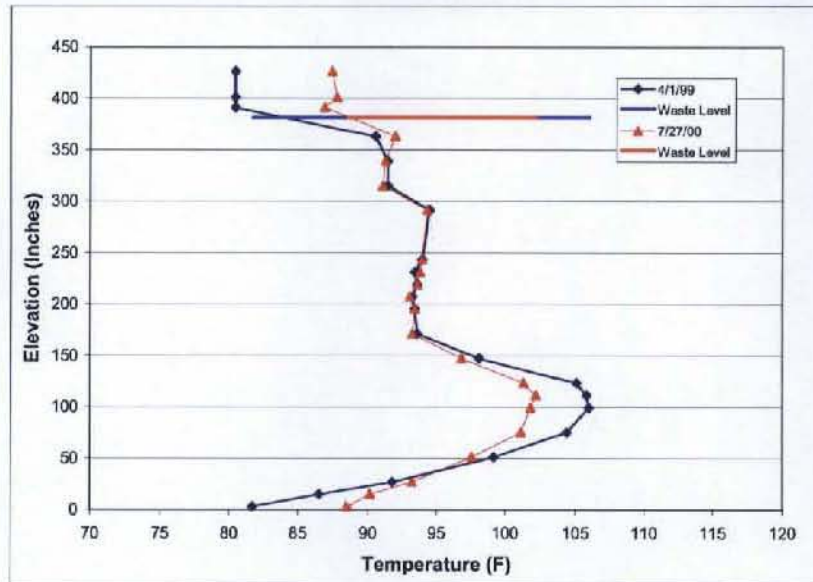
The Tank 241-AN-103 waste temperature profiles during April 1999 and July 2000 are shown in Figure 4-76 (TWINS 2007). Tank 241-AN-103 has a surface crust as discussed in Section 4.3.12, which controls the CO₂ absorption rate for both periods shown in Figure 4-72. The evaluation presented in Section 4.3.12 was used for the 1999 and July 2000 241-AN Farm ventilation evaluation.

Figure 4-76 Tank 241-AN-103 April 1999 and July 2000 Waste Temperature Profiles.

4.3.17.4 Tank 241-AN-104

The Tank 241-AN-104 waste temperature profiles during April 1999 and July 2000 are shown in Figure 4-77 (TWINS 2007). Tank 241-AN-104 has a surface crust as discussed in Section 3.2.1, which controls the CO₂ absorption rate for both periods shown in Figure 4-72. The evaluation presented in Section 3.2.1 is used for the 1999 and July 2000 241-AN Farm ventilation evaluation.

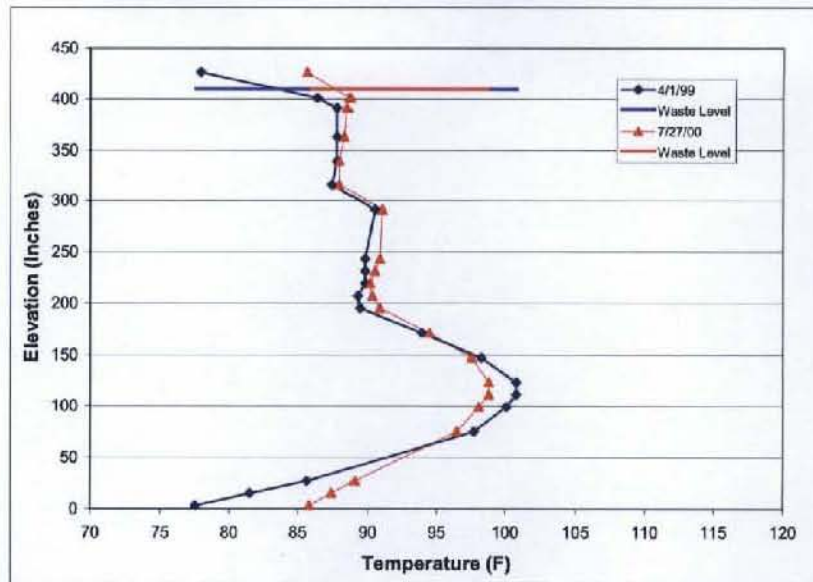
Figure 4-77 Tank 241-AN-104 April 1999 and July 2000 Waste Temperature Profiles.



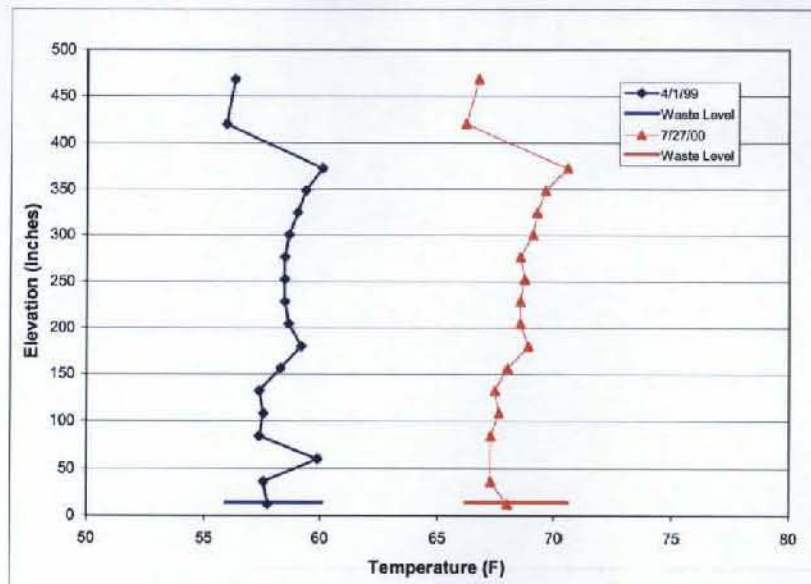
4.3.17.5 Tank 241-AN-105

The Tank 241-AN-105 waste temperature profiles during April 1999 and July 2000 are shown in Figure 4-78 (TWINS 2007). Tank 241-AN-105 has a surface crust as discussed in Section 3.2.2, which controls the CO₂ absorption rate for both periods shown in Figure 4-72. The evaluation presented in Section 3.2.2 is used for the 1999 and July 2000 241-AN Farm Ventilation system evaluation.

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Figure 4-78 Tank 241-AN-105 April 1999 and July 2000 Waste Temperature Profiles.**4.3.17.6 Tank 241-AN-106**

The Tank 241-AN-106 waste temperature profiles during April 1999 and July 2000 are shown in Figure 4-79 (TWINS 2007). There is little difference in the supernatant/vapor space temperature differences for the two periods shown in Figure 4-72. The evaluation presented in Section 4.3.15 is used for the 241-AN Farm ventilation evaluation for 1999 and July 2000.

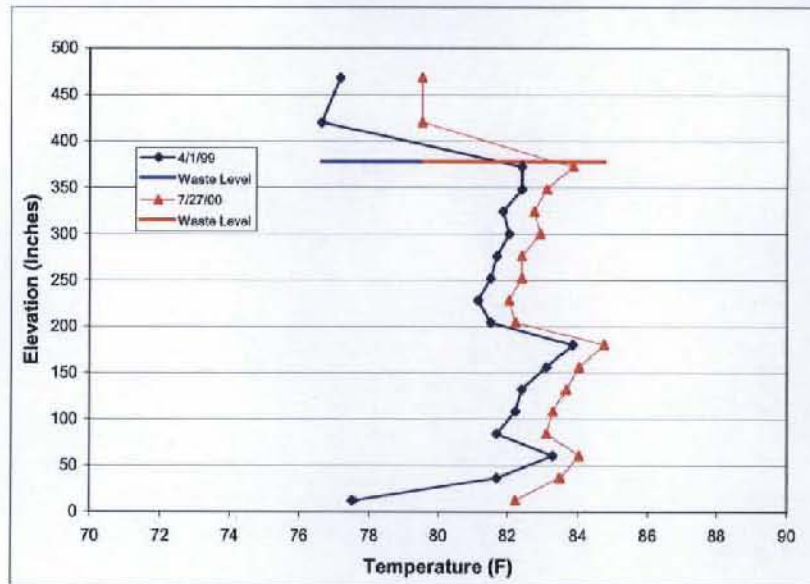
Figure 4-79 Tank 241-AN-106 April 1999 and July 2000 Waste Temperature Profiles.

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4.3.17.7 Tank 241-AN-107

The Tank 241-AN-107 waste temperature profiles during April 1999 and July 2000 are shown in Figure 4-80 (TWINS 2007). There is little difference in supernatant temperatures or supernatant/vapor space temperatures for the two periods shown in Figure 4-72. The evaluation presented in Section 4.3.16 is used for the 241-AN Farm ventilation evaluation for 1999 and July 2000.

Figure 4-80 Tank 241-AN-107 April 1999 and July 2000 Waste Temperature Profiles.

**4.3.17.8 241-AN Farm Ventilation System Results**

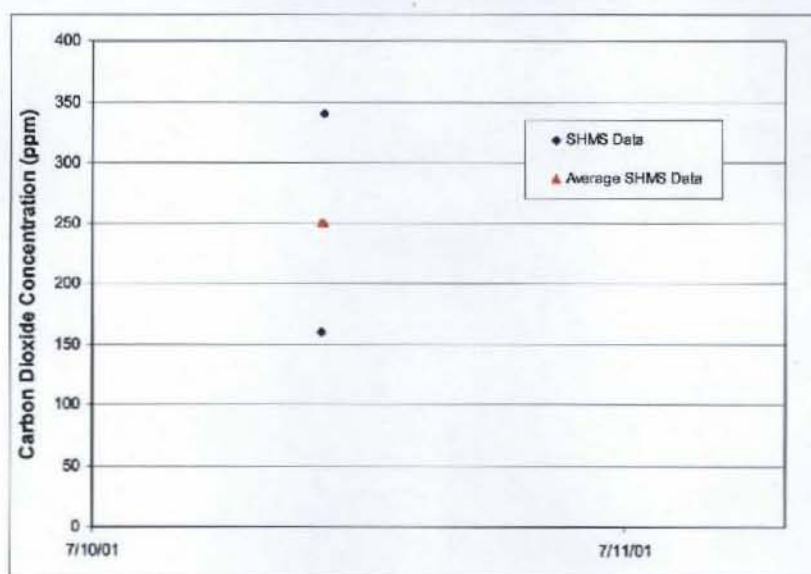
The mechanistic depletion model is used to predict the individual tank vapor space CO₂ concentrations for 1999 and July 2000. A flow weighted average provides a prediction of the 241-AN Farm ventilation air CO₂ concentrations for 1999 and July 2000. The results of the predicted ventilation air CO₂ concentration of 276 ppm are compared with the average measured data in Figure 4-81. There is reasonable agreement with the 1999 measured data. The predicted CO₂ concentration for July 2000 is 244 ppm, which is greater than the measured data.

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Figure 4-81 241-AN Farm Predicted and Measured Ventilation CO₂ Concentration.

4.3.18 Tank 241-AP-101

The Tank 241-AP-101 measured vapor space CO₂ concentrations for July 10, 2001, are shown in Figure 4-82 (TWINS 2007). The average value is 250 ppm. The mechanistic depletion model is used to predict the Tank 241-AP-101 vapor space CO₂ concentration.

Figure 4-82 Tank 241-AP-101 Measured Vapor Space CO₂ Concentration.

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The Tank 241-AP-101 supernatant OH⁻ ion concentration data for the December 1, 2000, sample event are shown in Figure 4-83 and Table 4-20 (TWINS 2007). Table 3-5 gives the data for the April 1, 2004, sample event shown in Figure 4-83. The supernatant OH⁻ ion concentration is high, 2.3 M.

Figure 4-83 Tank 241-AP-101 Waste Volume and Supernatant Hydroxide Data.

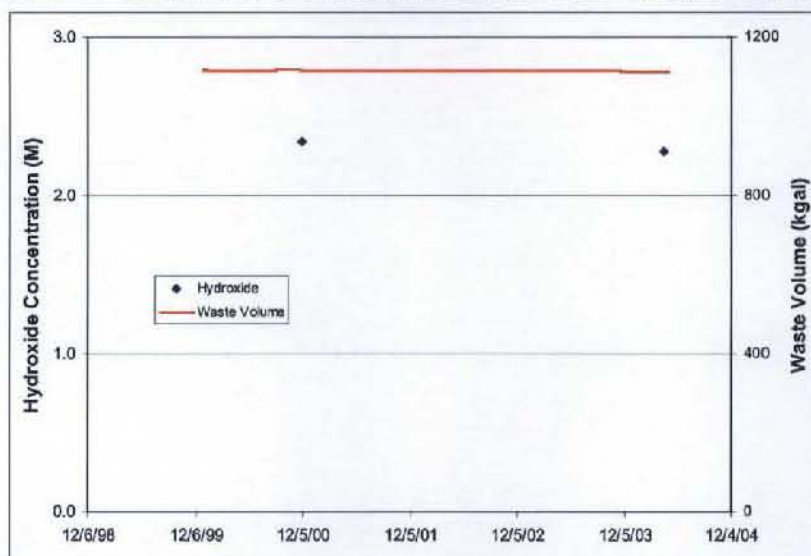


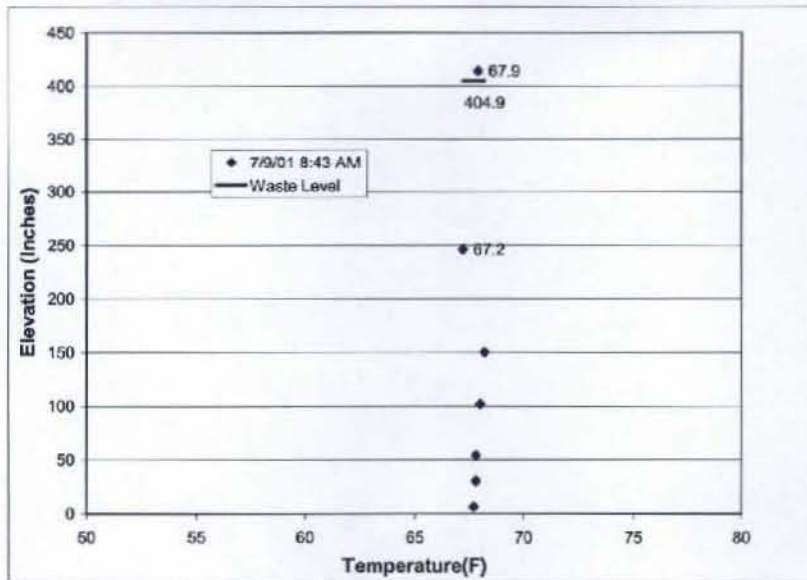
Table 4-20 Tank 241-AP-101 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Analysis Date	Measured Value (µg/mL)	Molarity	Average Value (M)	Document Location
241-AP-101	Liq Tank Composite	12/1/00	37800	2.22	2.34	RPP-8866, Rev. 0
241-AP-101	Liq Tank Composite	12/1/00	37200	2.19		RPP-8866, Rev. 0
241-AP-101	Tank Composite	12/1/00	41100	2.42		PNNL-13354
241-AP-101	Tank Composite	12/1/00	42300	2.49		PNNL-13354
241-AP-101	Tank Composite	12/1/00	40500	2.38		PNNL-13354

The Tank 241-AP-101 July 9, 2001, waste temperature profile is shown in Figure 4-84 (TWINS 2007). There are no temperature data available for the vapor space CO₂ measurement data of July 10, 2001. The supernatant/vapor space temperature difference is small and the vapor space temperature is larger than the supernatant. A value of 0.01 °F is used for the evaluation. This results in a low vapor side mass transfer coefficient.

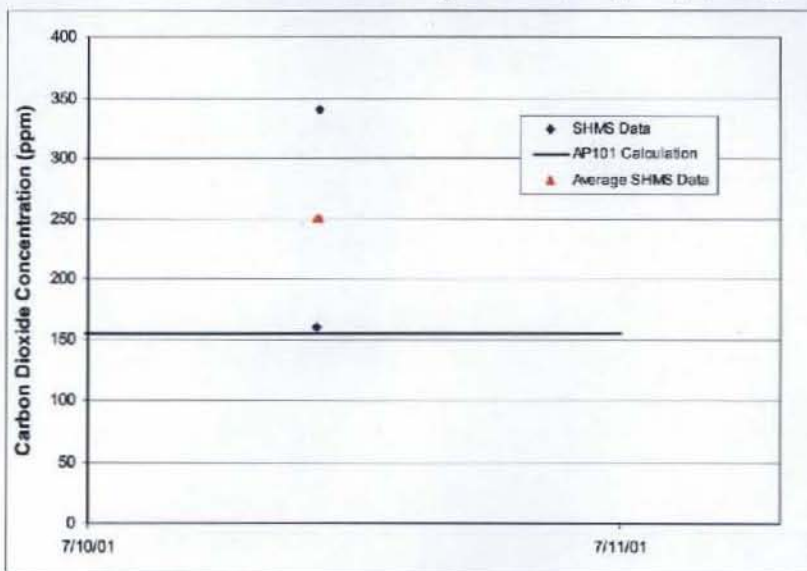
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Figure 4-84 Tank 241-AP-101 July 9, 2001, Waste Temperature Profile.



The mechanistic depletion model is used to predict the Tank 241-AP-101, vapor space CO₂ concentration for July 10, 2001. The predicted CO₂ concentration of 154 ppm is compared with the measured data in Figure 4-85. There is general agreement with the average data. However, the agreement is better with the lower measured value. The lower measured value is more consistent with both the measured Tank 241-AP-104 and 241-AP Farm ventilation system CO₂ concentrations discussed in Section 4.3.20 and 4.3.22, respectively.

Figure 4-85 Tank 241-AP-101 Predicted and Average Measured Vapor Space CO₂ Concentration.

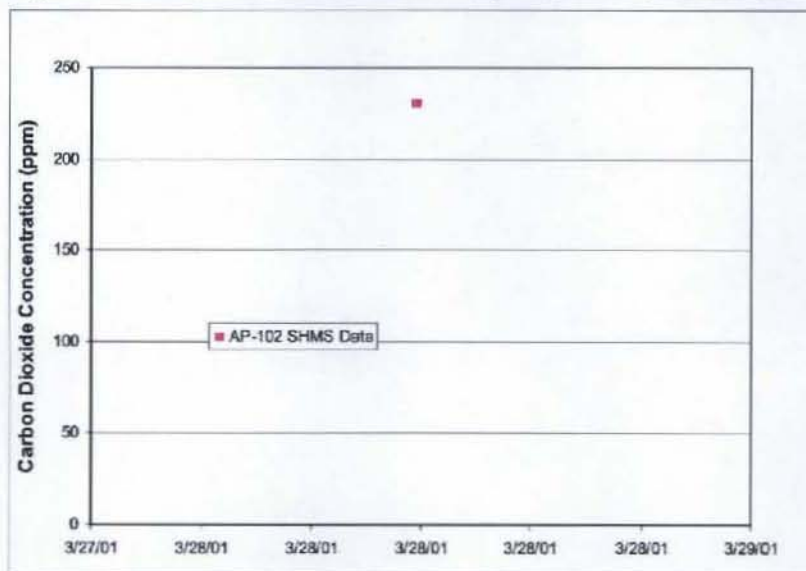


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4.3.19 Tank 241-AP-102

The Tank 241-AP-102 measured vapor space CO₂ concentrations for March 28, 2001, are shown in Figure 4-86 (TWINS 2007). The measured values are 230 ppm. The mechanistic depletion model is used to predict the Tank 241-AP-102 vapor space CO₂ concentration.

Figure 4-86 Tank 241-AP-102 Measured Vapor Space CO₂ Concentration.



The Tank 241-AP-102 supernatant OH⁻ ion concentration data are shown in Table 4-21 and Figure 4-87 (TWINS 2007). The supernatant OH⁻ ion concentration is 0.53 M.

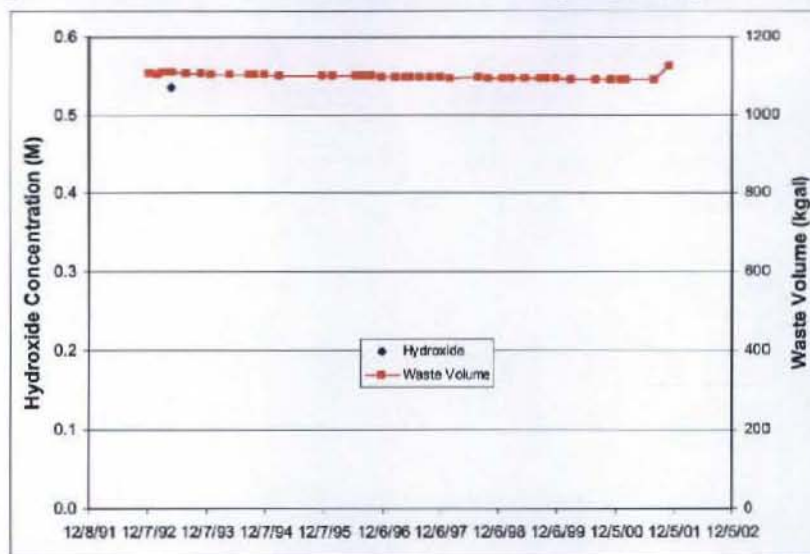
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Table 4-21 Tank 241-AP-102 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Analysis Date	Measured Value (µg/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-AP-102	Grab Sample	4/28/93	8940	0.526	0.535	WHC-SD-WM-DP-046, Rev. 0	G323
241-AP-102	Grab Sample	4/28/93	8940	0.526		WHC-SD-WM-DP-046, Rev. 0	G299
241-AP-102	Grab Sample	4/28/93	9130	0.537		WHC-SD-WM-DP-046, Rev. 0	G303
241-AP-102	Grab Sample	4/28/93	9520	0.560		WHC-SD-WM-DP-046, Rev. 0	G305
241-AP-102	Grab Sample	4/28/93	9470	0.557		WHC-SD-WM-DP-046, Rev. 0	G306
241-AP-102	Grab Sample	4/28/93	9080	0.534		WHC-SD-WM-DP-046, Rev. 0	G308
241-AP-102	Grab Sample	4/28/93	9400	0.553		WHC-SD-WM-DP-046, Rev. 0	G309
241-AP-102	Grab Sample	4/28/93	9080	0.534		WHC-SD-WM-DP-046, Rev. 0	G311
241-AP-102	Grab Sample	4/28/93	9200	0.541		WHC-SD-WM-DP-046, Rev. 0	G313
241-AP-102	Grab Sample	4/28/93	9330	0.549		WHC-SD-WM-DP-046, Rev. 0	G315
241-AP-102	Grab Sample	4/28/93	9080	0.534		WHC-SD-WM-DP-046, Rev. 0	G318
241-AP-102	Grab Sample	4/28/93	9080	0.534		WHC-SD-WM-DP-046, Rev. 0	G319
241-AP-102	Grab Sample	4/28/93	8690	0.511		WHC-SD-WM-DP-046, Rev. 0	G310
241-AP-102	Grab Sample	4/28/93	8810	0.518		WHC-SD-WM-DP-046, Rev. 0	G323
241-AP-102	Grab Sample	4/28/93	7910	0.465		WHC-SD-WM-DP-046, Rev. 0	G302
241-AP-102	Grab Sample	4/28/93	9330	0.549		WHC-SD-WM-DP-046, Rev. 0	G302
241-AP-102	Grab Sample	4/28/93	9400	0.553		WHC-SD-WM-DP-046, Rev. 0	G323
241-AP-102	Grab Sample	4/28/93	9080	0.534		WHC-SD-WM-DP-046, Rev. 0	G299
241-AP-102	Grab Sample	4/28/93	8940	0.526		WHC-SD-WM-DP-046, Rev. 0	G303
241-AP-102	Grab Sample	4/28/93	9010	0.530		WHC-SD-WM-DP-046, Rev. 0	G305
241-AP-102	Grab Sample	4/28/93	9200	0.541		WHC-SD-WM-DP-046, Rev. 0	G306
241-AP-102	Grab Sample	4/28/93	9200	0.541		WHC-SD-WM-DP-046, Rev. 0	G308
241-AP-102	Grab Sample	4/28/93	9080	0.534		WHC-SD-WM-DP-046, Rev. 0	G309
241-AP-102	Grab Sample	4/28/93	9080	0.534		WHC-SD-WM-DP-046, Rev. 0	G311
241-AP-102	Grab Sample	4/28/93	9200	0.541		WHC-SD-WM-DP-046, Rev. 0	G313
241-AP-102	Grab Sample	4/28/93	9150	0.538		WHC-SD-WM-DP-046, Rev. 0	G315
241-AP-102	Grab Sample	4/28/93	9270	0.545		WHC-SD-WM-DP-046, Rev. 0	G318
241-AP-102	Grab Sample	4/28/93	9080	0.534		WHC-SD-WM-DP-046, Rev. 0	G319
241-AP-102	Grab Sample	4/28/93	8940	0.526		WHC-SD-WM-DP-046, Rev. 0	G310
241-AP-102	Grab Sample	4/28/93	9080	0.534		WHC-SD-WM-DP-046, Rev. 0	G323
241-AP-102	Grab Sample	4/28/93	8810	0.518		WHC-SD-WM-DP-046, Rev. 0	G302
241-AP-102	Grab Sample	4/28/93	9330	0.549		WHC-SD-WM-DP-046, Rev. 0	G302

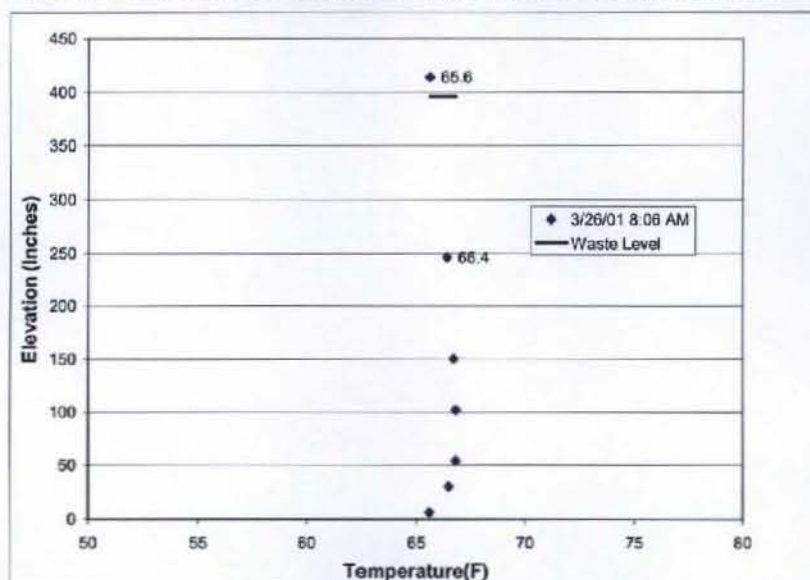
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Figure 4-87 Tank 241-AP-102 Waste Volume and Supernatant Hydroxide Data.



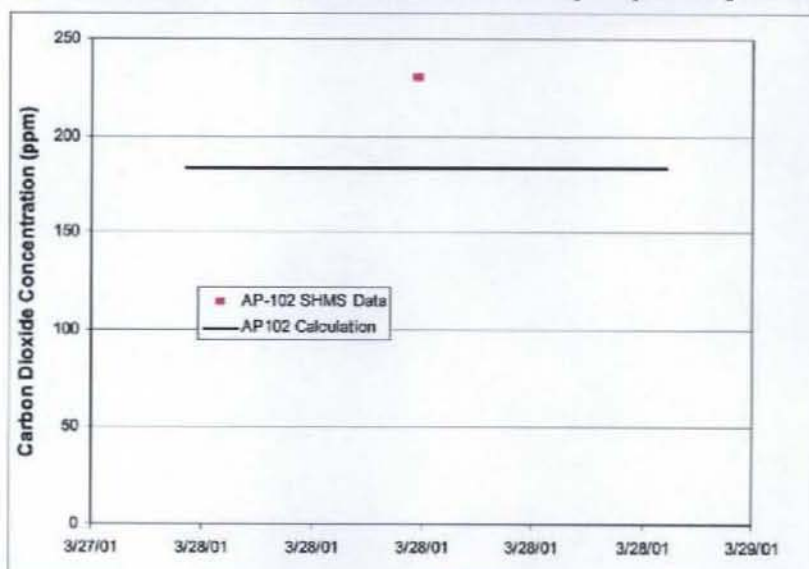
The Tank 241-AP-102 March 26, 2001, waste temperature profile is shown in Figure 4-8 (TWINS 2007). The supernatant/vapor space temperature difference is small, less than 1°F. A value of 0.01 °F is used for the evaluation. This results in a low vapor side mass transfer coefficient.

Figure 4-88 Tank 241-AP-102 March 26, 2001, Waste Temperature Profile.



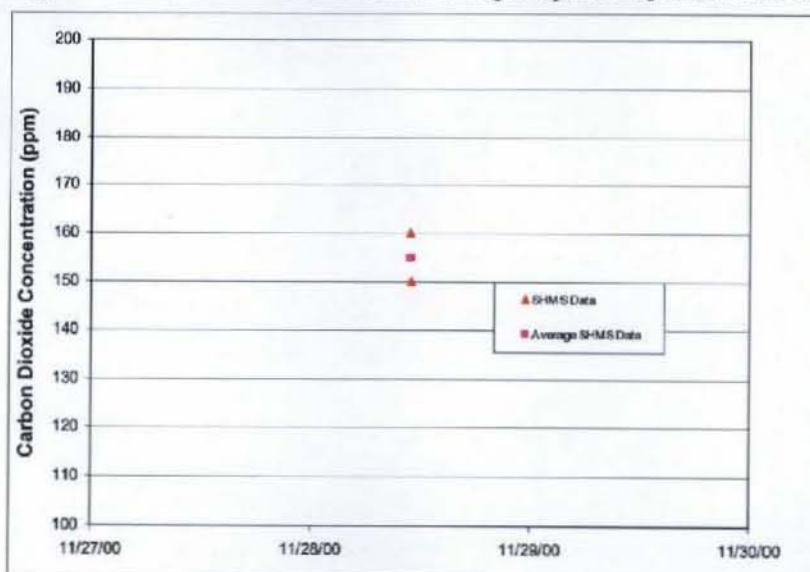
The mechanistic depletion model is used to predict the Tank 241-AP-102 vapor space CO₂ concentration for March 28, 2001. The predicted CO₂ concentration of 156 ppm is compared with the average measured data in Figure 4-89. There is reasonable agreement with the measured data.

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Figure 4-89 Tank 241-AP-102 Predicted and Measured Vapor Space CO₂ Concentration.

4.3.20 Tank 241-AP-104

The Tank 241-AP-104 measured vapor space CO₂ concentrations for November 28, 2000, are shown in Figure 4-90 (TWINS 2007). The measured average value is 155 ppm. The mechanistic depletion model is used to predict the Tank 241-AP-104 vapor space CO₂ concentration.

Figure 4-90 Tank 241-AP-104 Measured Vapor Space CO₂ Concentration.

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The Tank 241-AP-104 supernatant OH⁻ ion concentration data are shown in Table 4-22 and Figure 4-91 (TWINS 2007). The average supernatant OH⁻ ion concentration is near 1.3 M.

Figure 4-91 Tank 241-AP-104 Waste Volume and Supernatant Hydroxide Data.

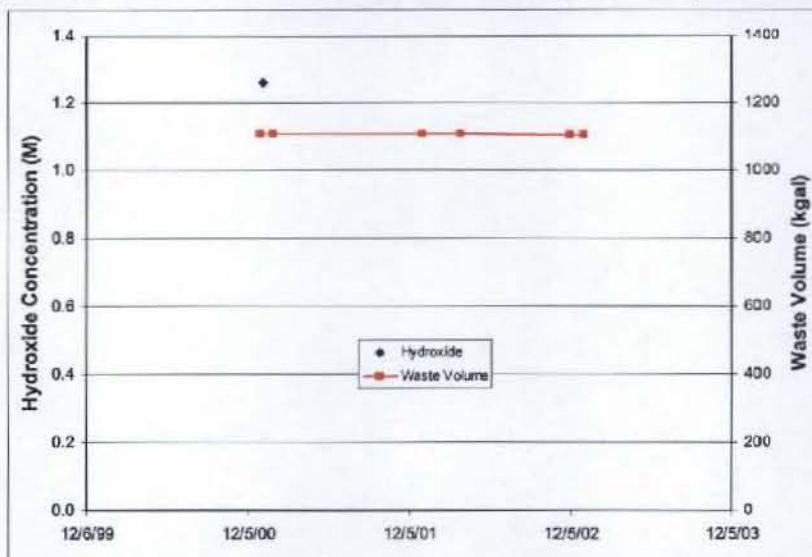


Table 4-22 Tank 241-AP-104 Measured Hydroxide Concentrations.

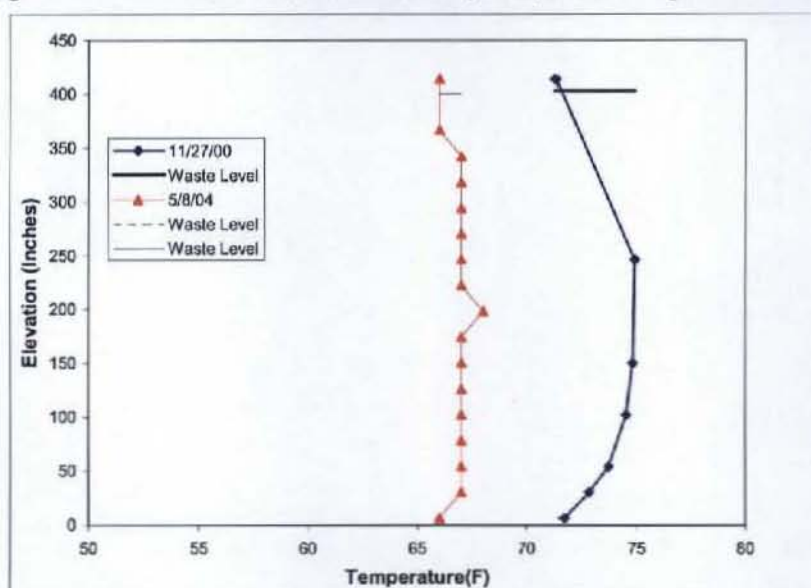
Tank Name	Aggregation Level	Sample Analysis Date	Measured Value (µg/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-AP-104	Tank Composite	1/9/2001	21500	1.26	1.26	HNF-7434 Rev. 0	Tank Comp Triple 2
241-AP-104	Tank Composite	1/9/2001	18800	1.11		HNF-7434 Rev. 0	Tank Comp Triple 3
241-AP-104	Tank Composite	1/9/2001	21500	1.26		HNF-7434 Rev. 0	Tank Comp Triple 1
241-AP-104	Tank Composite	1/9/2001	21600	1.27		PNWD-3334/WTP-RPT-069, Rev. 0	WTP Liquid Composite
241-AP-104	Tank Composite	1/9/2001	23100	1.36		PNWD-3334/WTP-RPT-069, Rev. 0	WTP Liquid Composite
241-AP-104	Tank Composite	1/9/2001	22200	1.31		PNWD-3334/WTP-RPT-069, Rev. 0	WTP Liquid Composite

The Tank 241-AP-104 November 27, 2000, waste temperature profile is shown in Figure 4-92 (TWINS 2007). The waste temperature profile for May 8, 2004, is also shown because more thermocouple data are available. The temperature throughout the waste is nearly uniform. The supernatant/vapor space temperature difference is small and assumed to be less than 1°F.

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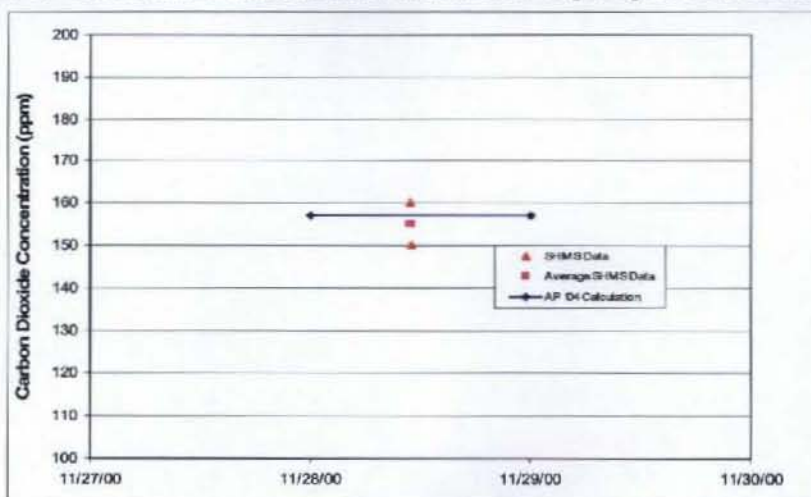
Consistent with the other 241-AP Farm tanks, Tank 241-AP-104 has a low tank heat load and, therefore, low heat and mass transfer rates at the liquid/vapor interface. A small supernatant/vapor space temperature difference (0.01 °F) will be used for the mechanistic depletion model.

Figure 4-92 Tank 241-AP-104 November 27, 2000, Waste Temperature Profile.



The mechanistic depletion model is used to predict the Tank 241-AP-104 vapor space CO₂ concentration for November 28, 2000. The predicted CO₂ concentration is compared with the average measured data in Figure 4-93. The predicted vapor space CO₂ concentration is 157 ppm. This is in excellent agreement with the average measured data.

Figure 4-93 Tank 241-AP-104 Predicted and Measured Vapor Space CO₂ Concentration.

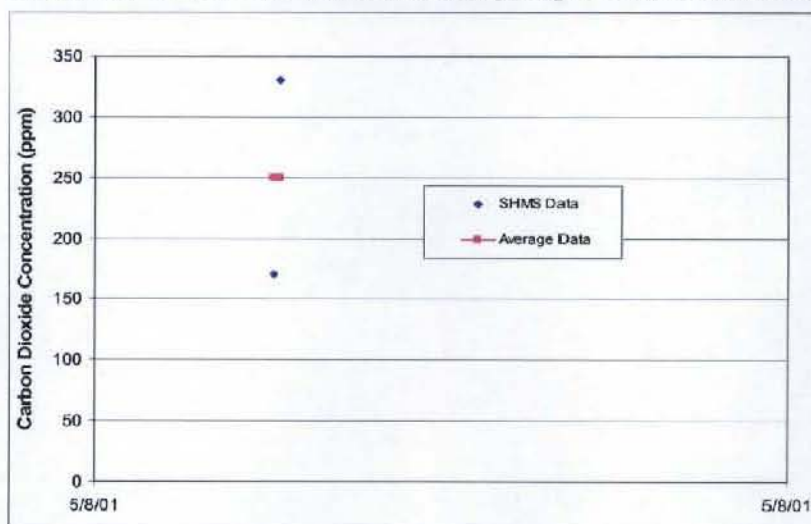


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4.3.21 Tank 241-AP-106

The Tank 241-AP-106 measured vapor space CO₂ concentrations for May 8, 2001, are shown in Figure 4-94 (TWINS 2007). The average measured value is 250 ppm. The mechanistic depletion model is used to predict the Tank 241-AP-106 vapor space CO₂ concentration.

Figure 4-94 Tank 241-AP-106 Measured Vapor Space CO₂ Concentration.



The Tank 241-AP-106 supernatant OH⁻ ion concentration data are shown in Table 4-23 and Figure 4-95 (TWINS 2007). Waste from Tank 241-SY-102 was transferred in Tank 241-AP-106 in March 2000 as shown in Figure 4-95. The supernatant OH⁻ ion concentration data shown in Table 4-23 and Figure 4-95 is the Tank 241-SY-102 value prior to the transfer. The average value is 1.2 M.

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Figure 4-95 Tank 241-AP-106 Waste Volume and Supernatant Hydroxide Data.

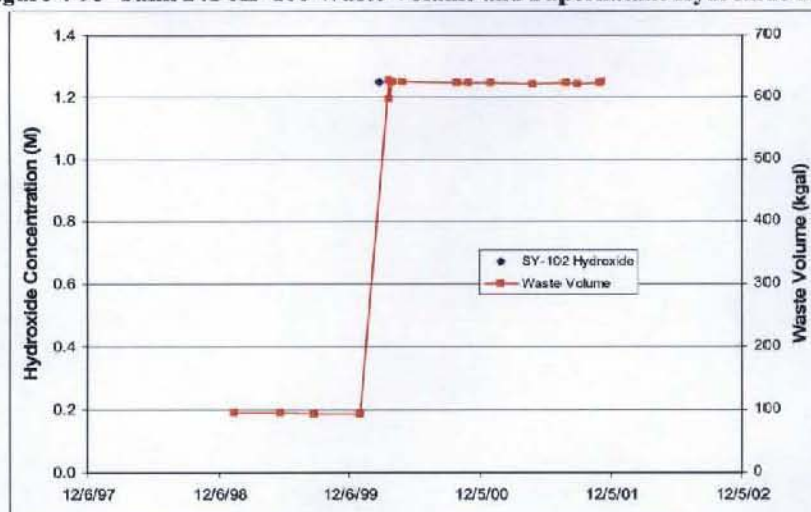
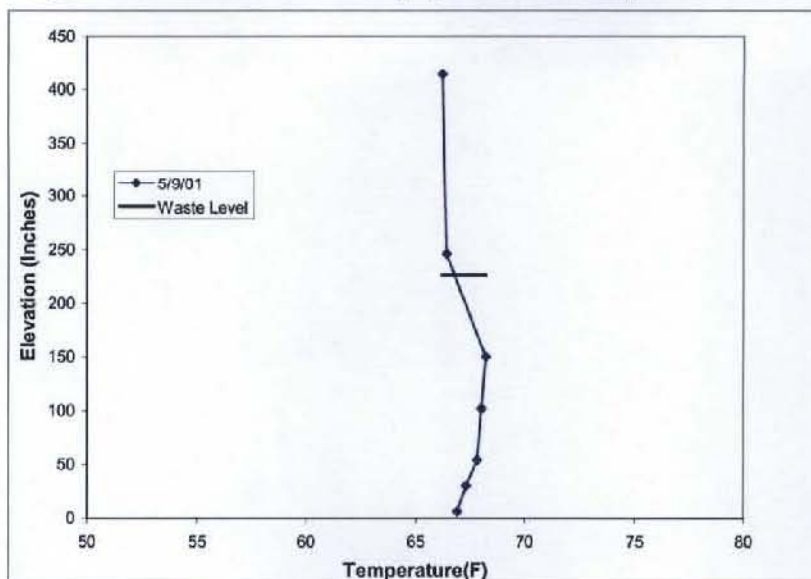


Table 4-23 Tank 241-AP-106 Measured Hydroxide Concentrations.

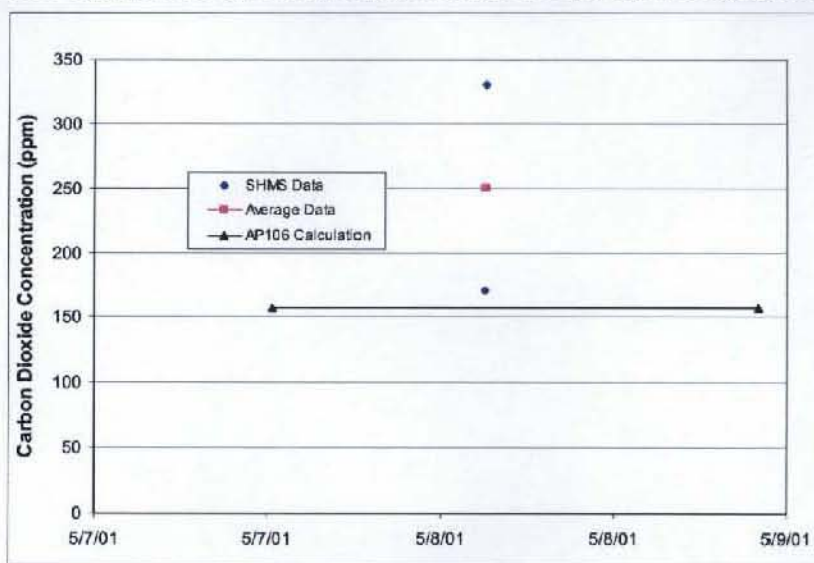
Tank Name	Aggregation Level	Sample Analysis Date	Measured Value (µg/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-SY-102	Grab Sample	2/25/00	11400	0.67	1.24	HNF-1699 Rev. 0	2SY-00-1
241-SY-102	Grab Sample	2/25/00	24000	1.41		HNF-1699 Rev. 0	2SY-00-4
241-SY-102	Grab Sample	2/25/00	18800	1.11		HNF-1699 Rev. 0	2SY-00-3
241-SY-102	Grab Sample	2/25/00	24200	1.42		HNF-1699 Rev. 0	2SY-00-5
241-SY-102	Grab Sample	2/25/00	22600	1.33		HNF-1699 Rev. 0	2SY-00-4
241-SY-102	Grab Sample	2/25/00	18800	1.11		HNF-1699 Rev. 0	2SY-00-2
241-SY-102	Grab Sample	2/25/00	25400	1.49		HNF-1699 Rev. 0	2SY-00-5
241-SY-102	Grab Sample	2/25/00	11500	0.68		HNF-1699 Rev. 0	2SY-00-1
241-SY-102	Grab Sample	2/25/00	24400	1.44		HNF-1699 Rev. 0	2SY-00-4
241-SY-102	Grab Sample	2/25/00	18700	1.10		HNF-1699 Rev. 0	2SY-00-3
241-SY-102	Grab Sample	2/25/00	24700	1.45		HNF-1699 Rev. 0	2SY-00-5
241-SY-102	Grab Sample	2/25/00	24600	1.45		HNF-1699 Rev. 0	2SY-00-4
241-SY-102	Grab Sample	2/25/00	18800	1.11		HNF-1699 Rev. 0	2SY-00-2
241-SY-102	Grab Sample	2/25/00	26100	1.54		HNF-1699 Rev. 0	2SY-00-5

The Tank 241-AP-106 May 9, 2001, waste temperature profile is shown in Figure 4-96 (TWINS 2007). The supernatant/vapor space temperature difference is small. A temperature difference of 0.01 °F will be used, which is consistent with the other 241-AP Farm tanks.

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Figure 4-96 Tank 241-AP-106 May 9, 2001 Waste Temperature Profile.

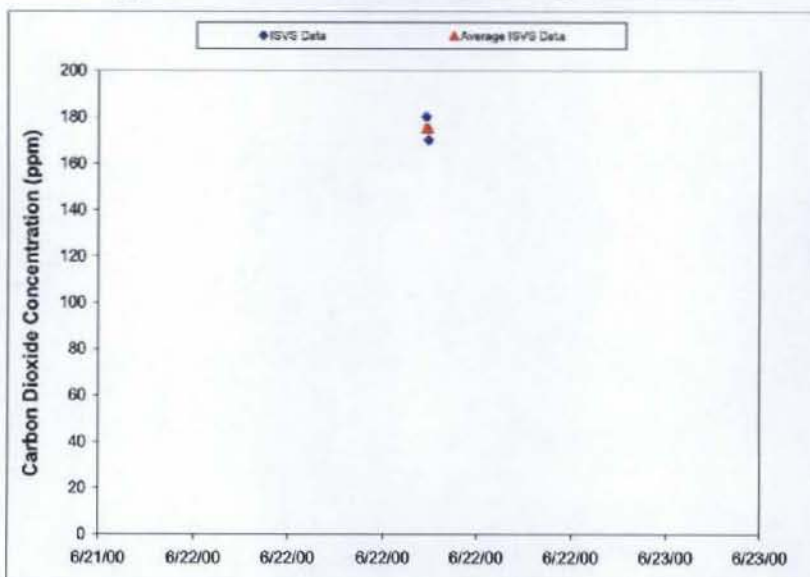
The mechanistic depletion model is used to predict the Tank 241-AP-106 vapor space CO₂ concentration for May 8, 2001. The predicted CO₂ concentration of 157 ppm is compared with the measured data in Figure 4-97. There is general agreement with the average data and excellent agreement with the lower data point. Both data points were measured within 5 minutes and should be nearly the same. The upper data may have been compromised in some way since its value is near ambient conditions. The lower data point is consistent with the Tank 241-AP-104 data shown in Figure 4-90.

Figure 4-97 Tank 241-AP-106 Predicted and Measured Vapor Space CO₂ Concentration.

4.3.22 241-AP Farm Ventilation System Carbon Dioxide Evaluation

Figure 4-98 shows the measured 241-AP Farm ventilation air CO₂ concentration for June 22, 2000 (TWINS 2007). The average measured concentration is 175 ppm. The mechanistic depletion model is used to predict the ventilation air CO₂ concentration. The calculated vapor space CO₂ concentration for Tanks 241-AP-101, 241-AP-102, 241-AP-104 and 241-AP-106 presented in the previous sections are used for the ventilation air evaluation. Additional analyses are performed in this section for the remaining 241-AP Farm tanks.

Figure 4-98 241-AP Farm Ventilation CO₂ Concentration.



4.3.22.1 Tank 241-AP-103

The 241-AP-103 waste volume and supernatant OH⁻ ion concentration are shown in Figure 4-99 and Table 4-24 (TWINS 2007). Supernatant OH⁻ ion concentration is near 0.6 M.

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Figure 4-99 Tank 241-AP-103 Waste Volume and Supernatant Hydroxide Data.

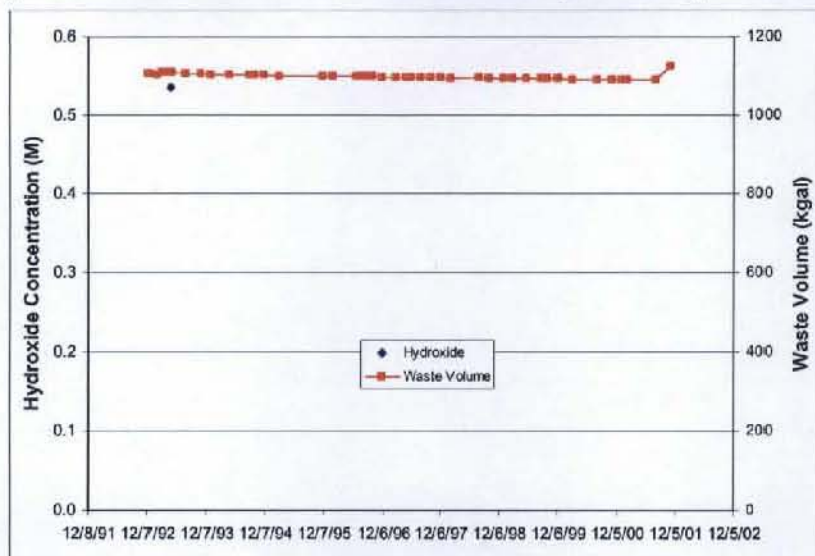


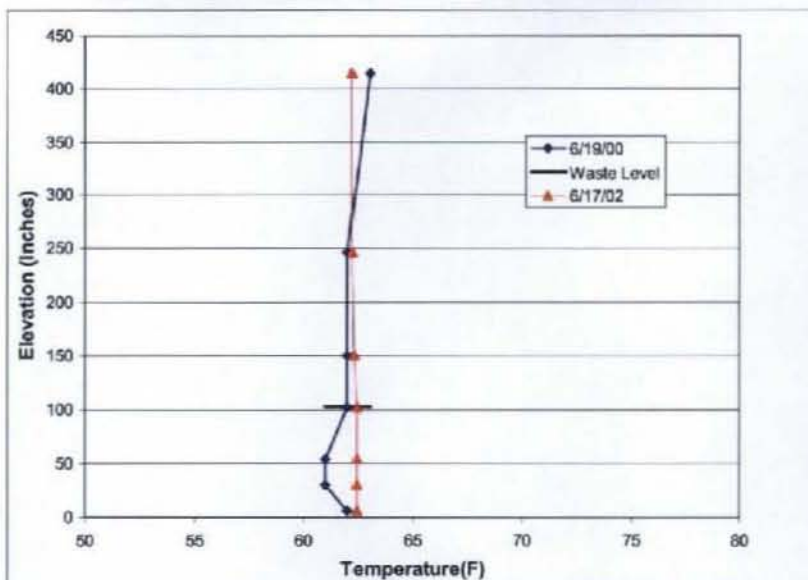
Table 4-24 Tank 241-AP-103 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Analysis Date	Measured Value (µg/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-AP-103	Grab Sample	8/12/99	8890	0.523	0.559	HNF-1683 Rev. 0	3AP-99-1
241-AP-103	Grab Sample	8/12/99	9560	0.562		HNF-1683 Rev. 0	3AP-99-3
241-AP-103	Grab Sample	8/12/99	9970	0.586		HNF-1683 Rev. 0	3AP-99-2
241-AP-103	Grab Sample	8/12/99	9500	0.559		HNF-1683 Rev. 0	3AP-99-1
241-AP-103	Grab Sample	8/12/99	9290	0.546		HNF-1683 Rev. 0	3AP-99-3
241-AP-103	Grab Sample	8/12/99	9830	0.578		HNF-1683 Rev. 0	3AP-99-2

Figure 4-100 shows the Tanks 241-AP-103 waste temperature profile for June 19, 2000, and June 17, 2002 (TWINS 2007). Consistent with the other 241-AP Farm tanks, the supernatant/vapor space temperature difference is small. A value of 0.01 °F is used for the evaluation. The mechanistic depletion model is used to predict the Tank 241-AP-103 vapor space CO₂ concentration for June 22, 2000. The predicted CO₂ concentration is 155 ppm.

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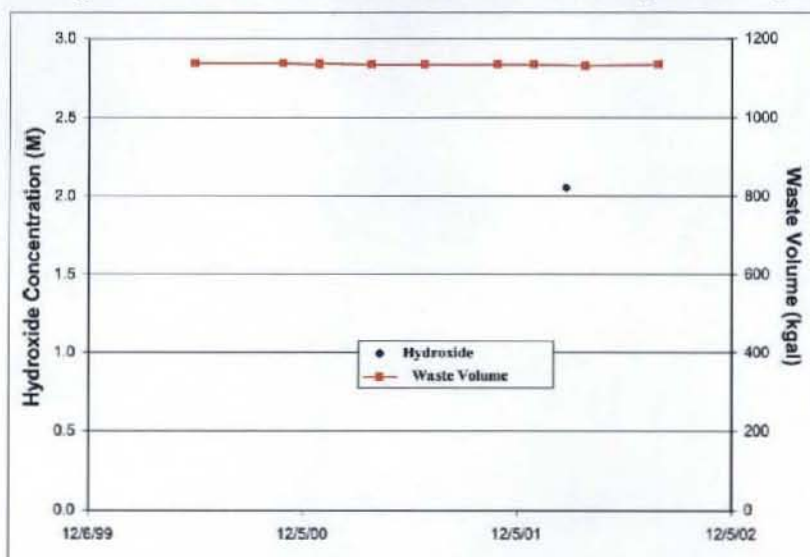
Figure 4-100 Tank 241-AP-103 Waste Temperature Profile.



4.3.22.2 Tank 241-AP-105

The 241-AP-105 waste volume and supernatant OH^- ion concentration are shown in Figure 4-101 and Table 4-25 (TWINS 2007). The supernatant OH^- ion concentration is over 2 M.

Figure 4-101 Tank 241-AP-105 Waste Volume and Supernatant Hydroxide Data.



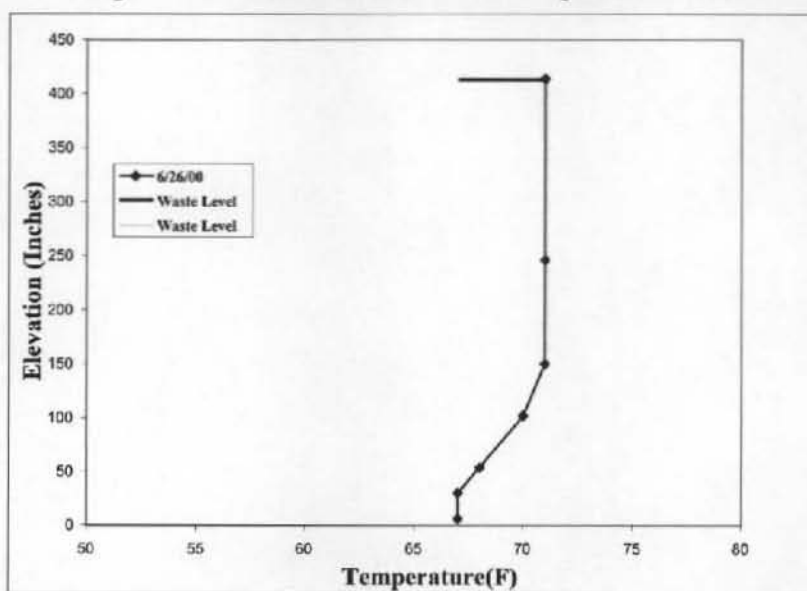
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Table 4-25 Tank 241-AP-105 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Date	Measured Value (ug/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name	Segment Name
241-AP-105	Drainable Liquid	2/26/02	34900	2.052	N/A	FH-0202231	301	1R

Figure 4-102 shows the Tanks 241-AP-105 waste temperature profile for June 26, 2000. The top thermocouple shown in Figure 4-102 is just above the waste surface. Consistent with the other 241-AP Farm tanks, the supernatant/vapor space temperature difference is small. A value of 0.01 °F is used for the evaluation. The mechanistic depletion model is used to predict the Tank 241-AP-105 vapor space CO₂ concentration for June 22, 2000. The predicted CO₂ concentration is 153 ppm.

Figure 4-102 Tank 241-AP-105 Waste Temperature Profile.



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4.3.22.3 Tank 241-AP-107

The 241-AP-107 waste volume and supernatant OH⁻ ion concentration are shown in Figure 4-103 and Table 4-26 (TWINS 2007). Supernatant OH⁻ ion concentration is near 0.6 M.

Figure 4-103 Tank 241-AP-107 Waste Volume and Supernatant Hydroxide Concentration.

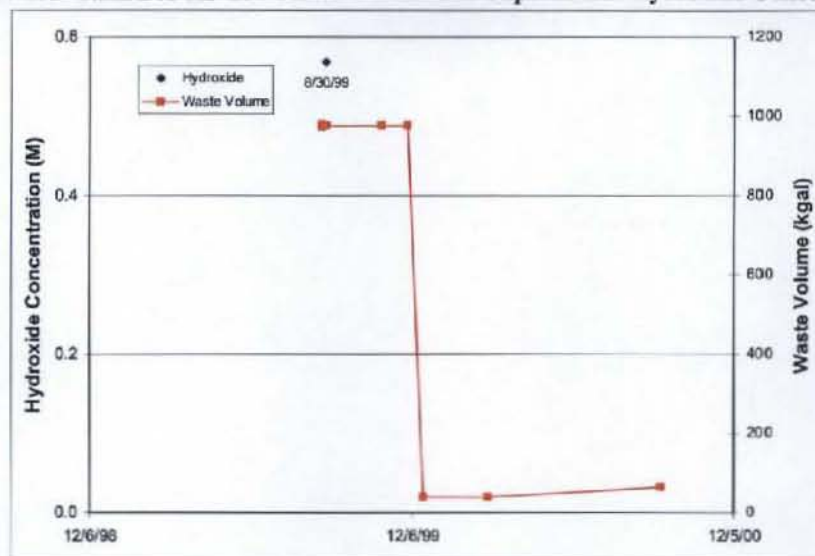


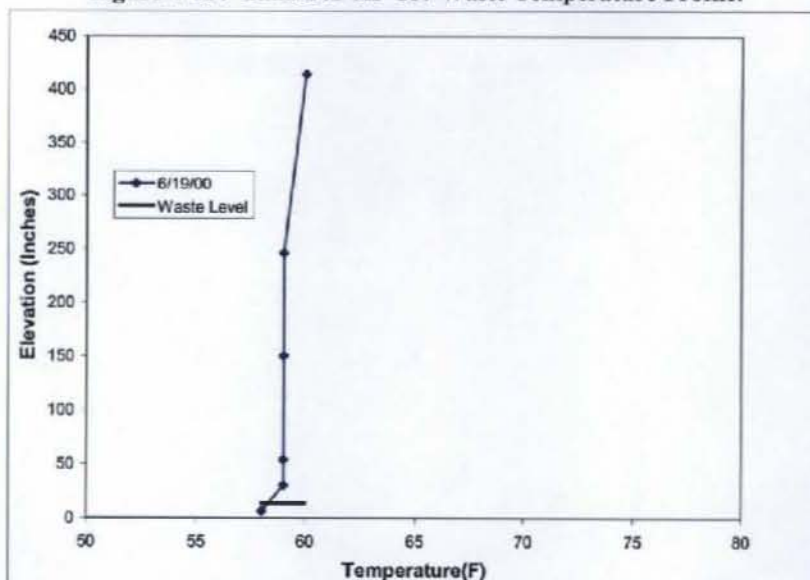
Table 4-26 Tank 241-AP-107 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Analysis Date	Measured Value (µg/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-AP-107	Grab Sample	8/30/99	9970	0.586	0.569	HNF-1689 Rev. 0	7AP-00-3C
241-AP-107	Grab Sample	8/30/99	9770	0.575		HNF-1689 Rev. 0	7AP-00-2C
241-AP-107	Grab Sample	8/30/99	9430	0.555		HNF-1689 Rev. 0	7AP-00-4C
241-AP-107	Grab Sample	8/30/99	9500	0.559		HNF-1689 Rev. 0	7AP-00-3C

Figure 4-104 shows the Tanks 241-AP-107 waste temperature profile for June 19, 2000 (TWINS 2007). Consistent with the other 241-AP Farm tanks, the supernatant/vapor space temperature difference is small. A value of 0.01 °F is used for the evaluation. The mechanistic depletion model is used to predict the Tank 241-AP-107 vapor space CO₂ concentration for June 22, 2000. The predicted CO₂ concentration is 155 ppm.

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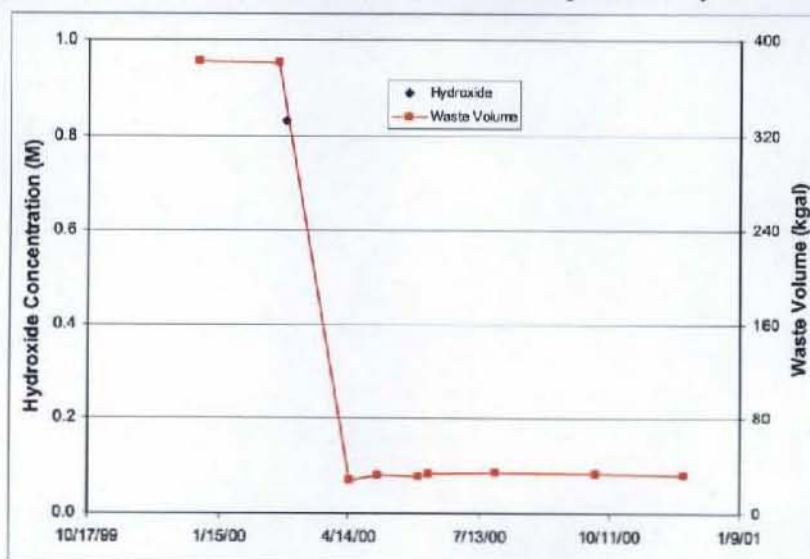
Figure 4-104 Tank 241-AP-107 Waste Temperature Profile.



4.3.22.4 Tank 241-AP-108

The 241-AP-108 waste volume and supernatant OH^- ion concentration are shown in Figure 4-105 and Table 4-27 (TWINS 2007). Supernatant OH^- ion concentration is 0.83 M.

Figure 4-105 Tank 241-AP-108 Waste Volume and Supernatant Hydroxide Data.



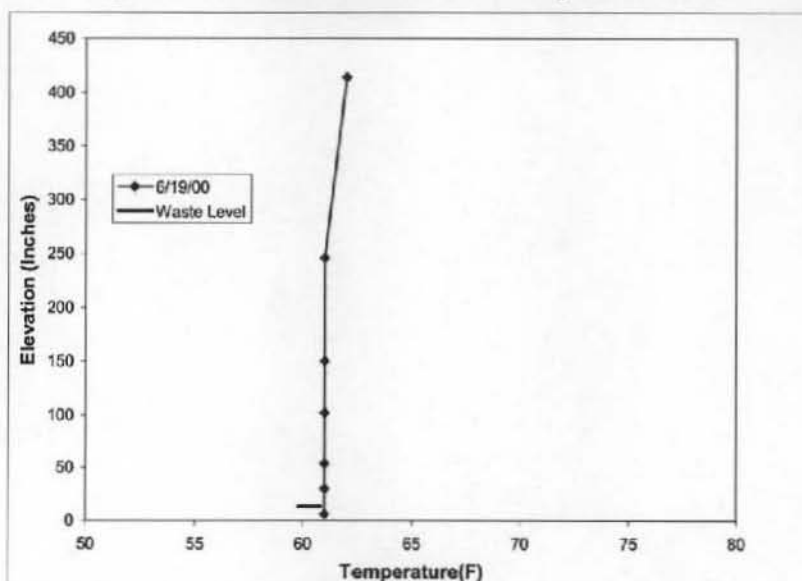
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Table 4-27 Tank 241-AP-108 Measured Hydroxide Concentrations.

Tank Name	Aggregation Level	Sample Analysis Date	Measured Value (ug/mL)	Molarity	Average Value (M)	Document Location	Sampling Event Name
241-AP-108	Grab Sample	3/1/00	14000	0.824	0.832	HNF-1694 Rev. 0	8AP-00-2C
241-AP-108	Grab Sample	3/1/00	14700	0.865		HNF-1694 Rev. 0	8AP-00-2C
241-AP-108	Grab Sample	3/1/00	13500	0.794		HNF-1694 Rev. 0	8AP-00-1C
241-AP-108	Grab Sample	3/1/00	14400	0.847		HNF-1694 Rev. 0	8AP-00-3C

Figure 4-106 shows the Tanks 241-AP-108 waste temperature profile for June 19, 2000 (TWINS 2007). Consistent with the other 241-AP Farm tanks, the supernatant/vapor space temperature difference is small. A value of 0.01 °F is used for the evaluation. The mechanistic depletion model is used to predict the Tank 241-AP-108 vapor space CO₂ concentration for June 22, 2000. The predicted CO₂ concentration is 152 ppm.

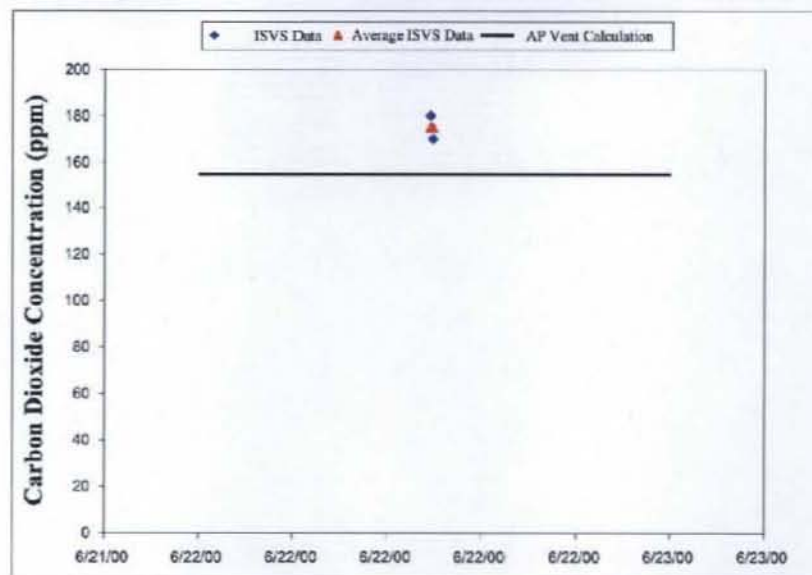
Figure 4-106 Tank 241-AP-108 Waste Temperature Profile.



4.3.22.5 241-AP Farm Ventilation System Results

The mechanistic depletion model was used to predict the vapor space CO₂ concentration of the individual tanks. The predicted 241-AP Farm ventilation air CO₂ concentration is the average of the individual tank vapor space CO₂ concentrations since the ventilation flow rates are assumed to be equal. The predicted and measured 241-AP Farm ventilation air CO₂ concentration is shown in Figure 4-107. The predicted value is 155 ppm. This is in excellent agreement with the average measured data value of 175 ppm.

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Figure 4-107 241-AP Farm Predicted and Measured Ventilation Air CO₂ Concentration.

4.3.23 Summary of SRS and Hanford Site Data Evaluations

The mechanistic depletion model is benchmarked with SRS data, Hanford Site supernatant OH⁻ ion concentration data, and Hanford Site DST vapor spaces and ventilation systems CO₂ data, as presented in Sections 3.0 and Sections 4.1 through 4.3. The mechanistic depletion model was benchmarked with nearly 50 data points. The results are summarized in Figure 4-108 by comparing the predicted OH⁻ ion depletion rate with the OH⁻ ion depletion rate derived from the data. The OH⁻ ion depletion rate for the Hobbs data is derived using Equation 4-2, which is an expansion of Equation 2-3.

$$(4-2) \quad OHdep_{hobbs} = 2 \cdot x_{CO_2_{air_amb}} \cdot C_{air} \cdot Q_{vent} \cdot F_{data}$$

Where:

$OHdep_{hobbs}$ = OH⁻ ion depletion rate for the Hobbs data [mole/unit time]

$x_{CO_2_{air_amb}}$ = CO₂ fraction in the ambient air

C_{air} = air molarity

Q_{vent} = ventilation flow rate [volume/unit time]

F_{data} = SRS CO₂ absorption fraction data

The OH⁻ ion depletion rate for the Hanford Site supernatant OH⁻ ion concentration data is derived from the slope of a linear curve fit to the OH⁻ ion data (Sections 3.2).

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The OH^- ion depletion rate for the Hanford Site CO_2 data is derived by Equation 4-3.

$$(4-3) \quad \text{OHdep}_{\text{CO}_2} = 2 \cdot x_{\text{CO}_2\text{air_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}} \cdot \left(1 - \frac{x_{\text{CO}_2\text{-data}}}{x_{\text{CO}_2\text{air_amb}}}\right)$$

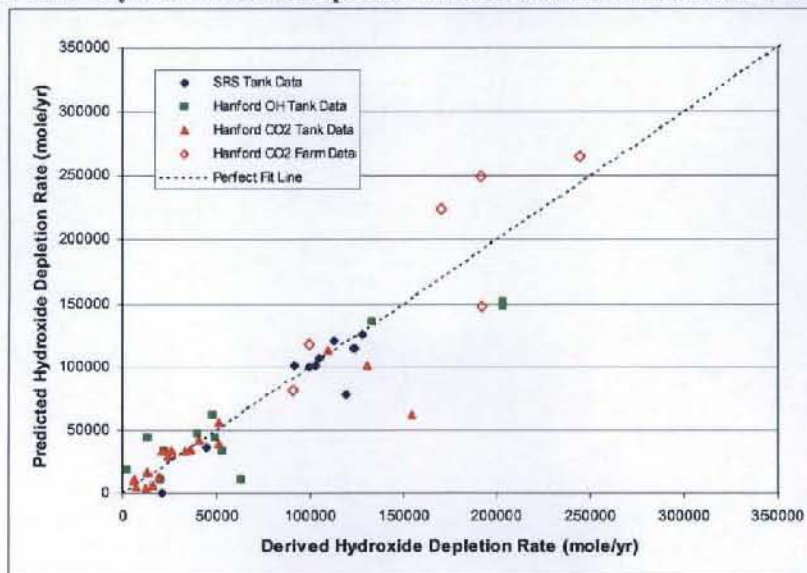
Where:

$\text{OHdep}_{\text{CO}_2}$ = OH^- ion depletion rate for the Hanford Site CO_2 data [mole/unit time]

$x_{\text{CO}_2\text{-data}}$ = Hanford Site DST vapor space and ventilation system CO_2 data
(what about the air_amb term?)

Figure 4-108 shows the predicted OH^- ion depletion rate for the SRS and Hanford Site data. The predicted values are compared to the derived OH^- ion depletion rates. The data are compared to the perfect fit line. The Hanford Site CO_2 data are plotted as individual tank data (vapor space CO_2 data) and tank farm ventilation system data, which is the CO_2 concentration for the air stream of the entire tank farm. The individual tank derived OH^- ion depletion rates range from just over 2000 mole/yr to 200,000 mole/yr. The tank farm ventilation system derived OH^- ion depletion rates range from 90,000 mole/yr to over 240,000 mole/yr. There is good agreement between the mechanistic depletion model predictions and the data for the individual tanks. The agreement is also excellent for the tank farm data.

Figure 4-108 Summary of Mechanistic Depletion Model Evaluation of SRS and Hanford Site Data.

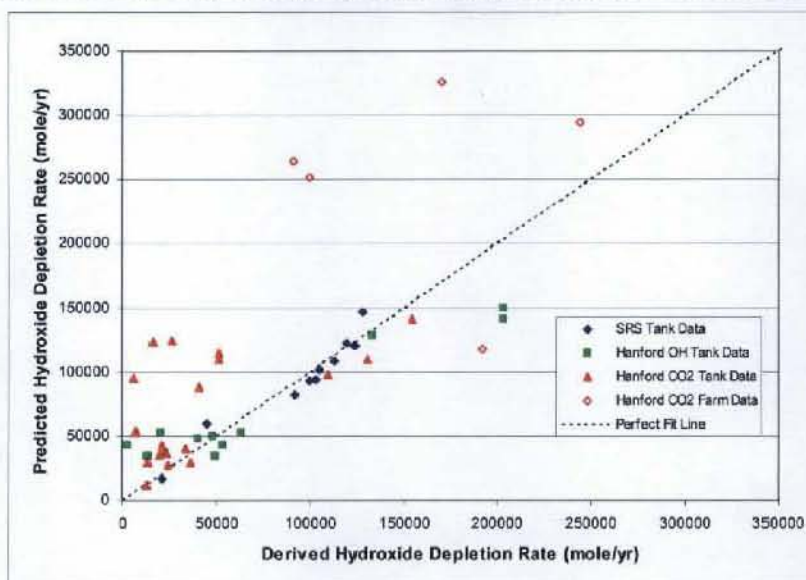


The Hobbs model discussed in Section 2.0 was also used to predict the OH^- ion depletion rates. The Hobbs model is an empirical model derived from the SRS data. As an empirical model it is valid within the context of the data from which it was derived. This model has been applied to Hanford Site waste tank evaluations in the past. It is being replaced by the mechanistic depletion

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model. Figure 4-109 shows a summary of the predicted OH^- ion depletion rates using the Hobbs model. The agreement with the SRS data is excellent since this is the data set used to derive the empirical correlation of the Hobbs model. The agreement with the Hanford Site supernatant OH^- ion data is also reasonable. However, the Hobbs model tends to over-predict the OH^- ion depletion rates for the Hanford Site individual DST and tank farm ventilation system CO_2 data. Because it is an empirical model, it is not applicable to the wide range of data represented in Figure 4-109.

Figure 4-109 Summary of Hobbs Model Evaluation of SRS and Hanford Site Data.



5.0 LABORATORY HYDROXIDE DEPLETION TESTS

A laboratory study was conducted to evaluate methods of measuring OH^- ion concentrations below 0.01 M , FH-0302630, *Report on the Evaluation of Potentiometric Titrations to Determine Hydroxide*. This study included an evaluation of effects of CO_2 absorption in a controlled laboratory environment. A test was performed at a 0.01 M sodium hydroxide level in which a small amount of the standard in a vial was exposed to the air by slowly stirring the sample. The OH^- ion concentrations were measured at 20 minute intervals for the duration of the test. The purpose of the test was to measure the effects of OH^- ion depletion by CO_2 absorption for small laboratory samples.

5.1 TEST DESCRIPTION

The test was conducted by placing 10 mL of 0.01 M sodium hydroxide solution in a scintillation vial, Carothers e-mail, Appendix C. A sketch of a typical scintillation vial is shown in Figure 5-1. The sample was slowly stirred during the test.

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The measured OH^- ion concentrations for the CO_2 absorption test are shown in Table 5-1. These data are shown graphically in Figure 5-2. The OH^- ion concentrations are measured every 20 min. during the duration of the one-hour test. The OH^- ion concentration decreases by nearly 60% during the test, due to CO_2 absorption. The depletion rate is nearly constant during the test. The average OH^- ion molar depletion rate is 0.000067 M/min as shown in Figure 5-2.

Figure 5-1 Scintillation Vial.

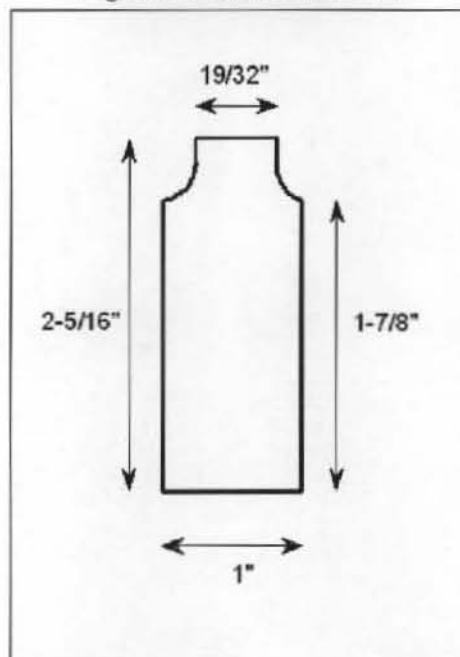


Table 5-1 Laboratory Test Data.

Time (min.)	$[\text{OH}]$ (M)
0	0.00963
0	0.00976
20	0.00832
20	0.00855
40	0.00689
40	0.00727
60	0.00575
60	0.00561

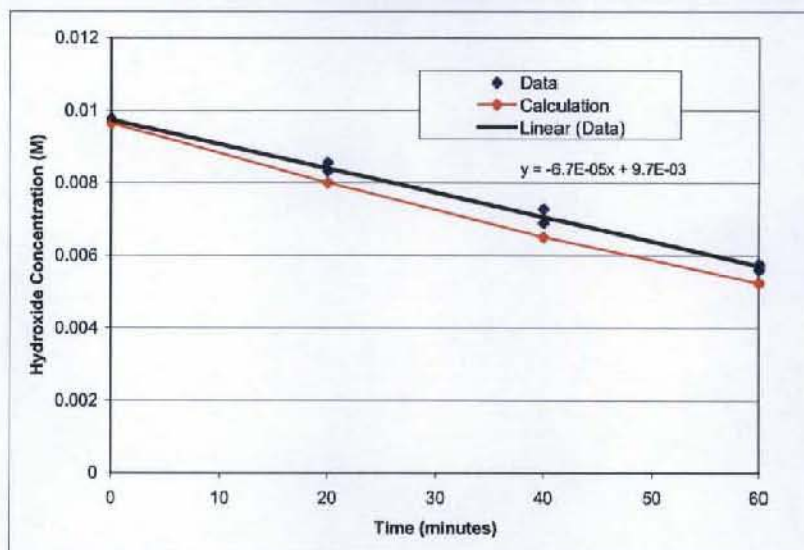
5.2 LABORATORY TEST BENCHMARK ANALYSES

The mechanistic depletion model presented in Section 2.0 is used to predict the OH^- ion depletion rate for the laboratory test. The OH^- ion concentration is then calculated for each 20 min. interval.

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The CO₂ absorption is small due to the small sample size. The CO₂ concentration in the ambient air of the laboratory would not be affected by the test. Therefore, an ambient CO₂ concentration of 360 ppm was assumed for the analyses. The sample was slowly stirred during the test. The OH⁻ ion mass transfer coefficient should then be based on convection rather than molecular diffusion. Since the stirring was gentle, it is appropriate to base the mass transfer coefficient on natural convection.

Figure 5-2 Comparison of Predicted and Measured Hydroxide Concentrations.



The predicted OH⁻ ion concentrations for the laboratory test are shown Figure 5-2. The predicted OH⁻ ion concentration decreases linearly at a rate slightly higher than the measured data. The predicted average OH⁻ ion depletion rate is 0.000074 M/min. This agrees well with the 0.000067 M/min rate derived from the data as shown in Figure 5-2. Therefore, the OH⁻ ion depletion rate for this laboratory scale test is well predicted by the mechanistic depletion model.

6.0 TANK 241-AZ-102 CORE 317 SEGMENT 18 EVALUATION

6.1 BACKGROUND

On June 29, 2005, Core 317 was taken in Tank 241-AZ-102. When the top sludge segment, Segment 18, was extruded in the hot cell, drainable liquid formed a pool on the tray holding the extruded sample. Subsequent measurements of the OH⁻ ion concentrations of the drainable liquid and upper half Segment 18 interstitial liquid showed that the interstitial liquid OH⁻ ion concentration was 0.01 M (pH 12), while the drainable liquid OH⁻ ion concentration was approximately 0.0032 M (pH 11.5). The minimum allowed OH⁻ ion concentration by AC 5.16 is 0.01 M. The interstitial liquid trapped in the inner pores of the solid core remained isolated from the ambient air; only the small fraction of interstitial liquid at the surface of the solid core was exposed to the ambient air for the extended time period the sample was on the tray. It was

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postulated that the OH^- ion concentrations of the drainable liquid and interstitial liquid were initially the same, given their common origin, but that the drainable liquid was depleted through CO_2 absorption while the drainable liquid was on the tray in the hot cell.

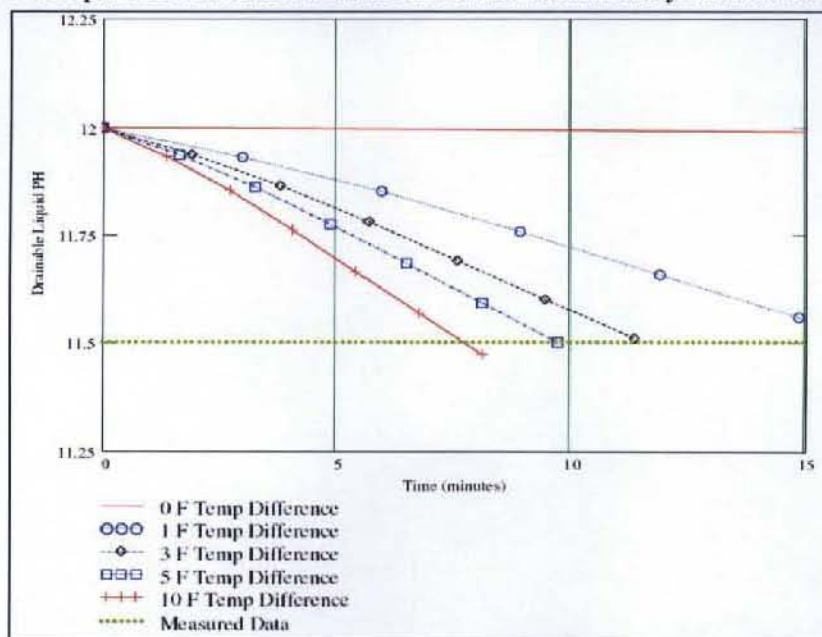
An evaluation was completed using the mechanistic hydroxide depletion model (Section 2.0) and documented in RPP-RPT- 27902, *Assessment of Tank 241-AZ-102 Compliance with Technical Safety Requirements Corrosion Mitigation Controls Chemistry Limits*. The evaluation determined how long it would take for the pH of the drainable liquid to drop from 12.0 (the measured value for the interstitial liquid) to 11.5 (the measured value of the drainable liquid) from exposure to the CO_2 from the hot cell ventilation air. This exposure time of the drainable liquid to ambient air is estimated to be from 5 min. to 20 min.

6.2 EVALUATION RESULTS

The results of the Core 317, Segment 18 evaluations, RPP-RPT-27902, are presented in Figure 6-1. The figure shows the results of the predicted drainable liquid pH. The initial pH is assumed to be the same as for Segment 18 upper half IL, pH 12. The drainable liquid pH is predicted to decrease to the measured value of 11.5 in 5 to 15 minutes assuming that the temperature difference between the drainable liquid and hot cell air temperature is 2 °F or greater. Given the initial temperature of Segment 18 (~ 137 °F), and method and timeliness of sample retrieval from the tank, packaging, transport to the hot cell, and extrusion (within a 5-hour period), a temperature difference of 10 °F or more does not seem unreasonable.

The analyses suggest that the measured pH for the drainable liquid compared to the interstitial liquid is consistent with OH^- ion depletion that would be expected to occur in the hot cell as predicted by the mechanistic hydroxide depletion model presented in Section 2.0.

Figure 6-1 Comparison Tank 241-AZ-102 Predicted and Measured Hydroxide Concentrations.



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7.0 CONCLUSIONS

- Both the Hobbs model and the mechanistic hydroxide depletion model provide reasonable CO₂ absorption fraction predictions for the SRS H-Area tanks and the Hanford Site DSTs.
- The mechanistic hydroxide depletion model more accurately predicts the OH⁻ ion depletion rate for the Hanford Site tanks as the model accounts for important physical parameters in addition to OH⁻ ion concentrations.
- The mechanistic hydroxide depletion model has been implemented and used to evaluate OH⁻ ion concentration long-term trends for some of the 28 DSTs. Continued application of the model to address OH⁻ ion depletion in all non-operational DSTs will be beneficial in determining an optimum sampling schedule for DSTs to verify continued compliance with AC 5.16 chemistry control limits and plan preventative actions for tanks that are approaching the chemistry limits.
- The paucity, scatter and uncertainty in the Hanford Site DST OH⁻ ion concentration data used to benchmark the mechanistic OH⁻ ion depletion model requires continued comparison of model predictions with actual depletion rates determined from DST sample data to verify accuracy of the model. This continued model improvement will satisfy the following expert panel findings from RPP-RPT-22126;
 - “Core samples from the sludge will need to be withdrawn to establish that the concentrations of the corrosion inhibitors (hydroxide ion and nitrite ion) are appropriate for corrosion control and that their rates of consumption are suitably low.”
 - “Core sampling will also be necessary to verify the predictions of the combined chemical consumption and chemical mixing model that will eventually be used to determine the (sampling) scheduling frequency.”
- Accurate vapor space and supernatant temperatures are required for applying the hydroxide depletion model to DSTs. Temperature instrumentation that provides capability to monitor long-term trends and generate tank profiles needs to be maintained in operating condition and, where absent, e.g., 241-AP Farm tank vapor space thermocouples, re-configured to obtain the required measurements.
- Accurate DST ventilation flow rate data are required for applying the hydroxide depletion model to DSTs. Assumed ventilation flows need to be periodically verified either through engineering analysis, or preferably from field measurements, to provide updated inputs to the model.
- Consideration should be given for periodically obtaining CO₂ measurements of DST ventilation air under test control conditions to reduce the uncertainty in the current CO₂ database and, thereby, improve the validation of the hydroxide depletion model and confirm its accuracy. As a minimum, DST with no CO₂ or limited CO₂ data, as identified in this report, should have their headspace or ventilation air CO₂ concentrations measured.

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APPENDIX A

JOHN MARVIN, INC REVIEWERS CHECKLIST

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Engineering Report: RPP-26676, Rev. 1

Title: DOUBLE-SHELL TANK HYDROXIDE DEPLETION MODEL FOR CARBON DIOXIDE ABSORPTION

1.	Is the purpose of the engineering analysis clearly stated?	Yes		
2.	Are required inputs and information sources provided?	Yes		
3.	Is the methodology clearly identified?	Yes		
4.	Have the limits of applicability been identified?	Yes		
5.	Is all supporting data/information referenced or provided in the project files?	Yes		
6.	Are the assumptions and conservatism's clearly identified?	Yes		
7.	Are all calculation notes or engineering notes uniquely identified and pages sequentially numbered?	Yes		
8.	Are the computer codes and models identified?			NA
9.	Are all computer analyses clearly identified?			NA
10.	Were the computer codes under configuration control?			NA
11.	Were the computer codes and models applicable for the stated purpose of the analyses?	Yes		
12.	Are the results and conclusions clearly presented?	Yes		
13.	Are open technical issues properly identified?			NA
14.	Were customer organization Design Control practices followed?	Yes		

Note: If NO to any of the above, identify justification on attached page or reference report or notebook page #.

CHECKED BY: Marvin J. Thurgood

Date: 9/24/07



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APPENDIX B

**JMI-NB-5010101
CAUSTIC DEPLETION MECHANISTIC MODEL ENGINEERING NOTEBOOK**

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Subcontractor Calculation Review Checklist

Page 1 of 1

Subject: Caustic Depletion Mechanistic Model Engineering Notebook

The subject document has been reviewed by the undersigned.
The reviewer reviewed and verified the following items as applicable.

Documents Reviewed: JMI-NB-5010101Analysis Performed By: D. M. Ogden and M. J. Thurgood, John Marvin, Inc.

- Design Input
- Basic Assumptions
- Approach/Design Methodology
- Consistency with item or document supported by the calculation
- Conclusion/Results Interpretation
- Impact on existing requirements
- _____

Reviewer (printed name and signature)

K. G. Carothers KG Carothers Date: 10/29/07

Organizational Manager (printed name and signature)

N. W. Kirch NW Kirch Date: 10/29/2007

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CAUSTIC DEPLETION
MECHANISTIC MODEL
ENGINEERING NOTEBOOK

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CAUSTIC DEPLETION MECHANISTIC MODEL BENCHMARK ENGINEERING NOTEBOOK

Prepared by
D.M. OgdenReviewed by
Marvin J Thurgood

September 2007

Approved JMI President

Marvin J Thurgood



Date: 9/27/2007

Approved JMI QA Manager

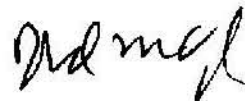
Donald M Ogden



Date: 9/27/2007

Approved JMI Engineer

Donald M Ogden



Date: 9/27/2007

Approved JMI Reviewer

Marvin J Thurgood



Date: 9/27/2007

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CAUSTIC DEPLETION
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NOTEBOOK REVIEW CHECKLIST

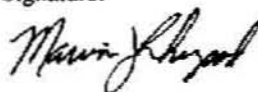
Engineering Notebook No. JMI-NB-05010101, Rev 1Title: **CAUSTIC DEPLETION MECHANISTIC MODEL ENGINEERING**

1.	Is the purpose of the engineering analysis clearly stated?	Yes		
2.	Are required inputs and information sources provided?	Yes		
3.	Is the methodology clearly identified?	Yes		
4.	Have the limits of applicability been identified?	Yes		
5.	Is all supporting data/information referenced or provided in the project files?	Yes		
6.	Are the assumptions and conservatism's clearly identified?	Yes		
7.	Are all calculation notes or engineering notes uniquely identified and pages sequentially numbered?	Yes		
8.	Are the computer codes and models identified?	Yes		
9.	Are all computer analyses clearly identified?	Yes		
10.	Were the computer codes under configuration control?	NA		
11.	Were the computer codes and models applicable for the stated purpose of the analyses?	Yes		
12.	Are the results and conclusions clearly presented?	Yes		
13.	Are open technical issues properly identified?	Yes		
14.	Were customer organization Design Control practices followed?	Yes		

Note: If NO to any of the above, identify justification on attached page or reference report or notebook page #.

CHECKED BY: Marvin J. ThurgoodDate: 9/27/2007

Signature:



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CAUSTIC DEPLETION
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1.0 INTRODUCTION

Administrative Control (AC) 5.16 is a part of the Technical Safety Requirements (TSRs) for the double-shell tanks (DSTs) and aging waste facility (AWF) tanks, HNF-SD-WM-TSR-006, Tank Farms Technical Safety Requirements. Administrative Control 5.16 requires a program be maintained to manage the DST waste chemistry to limit corrosion of the primary tank wall. The technical basis for the chemistry control program is documented in RPP-7795, *Technical Basis for Chemistry Control Program*.

Maintaining a minimum specified free hydroxide ion (OH^-) concentration in DST waste is central to the chemistry control program. The free OH^- ion is consumed or depleted through chemical reactions. Chemical reactions include the depletion of free OH^- ion through the absorption of carbon dioxide (CO_2) from the tank ventilation air. The current technical basis identifies the Hobbs equation as the free OH^- depletion model for CO_2 absorption, DPST-87-596, *Absorption of Carbon Dioxide in Waste Tanks (U)*. The Hobbs model is an empirical correlation of measured CO_2 absorption rate data (based on solution pH) for eight H-area tanks from the U.S. Department of Energy, Savannah River Site (SRS). The Hobbs correlation is not a mechanistic based model.

The objective of this document is to present a free hydroxide depletion model for carbon dioxide absorption which is mechanistically based and which has been benchmarked using Hanford waste tank data.

The evaluation of the mechanistic hydroxide depletion model is documented in RPP-26676, *Double-Shell Tank Hydroxide Depletion Model for Carbon Dioxide Absorption*. The Hanford site tank data and the Savannah River Site data used for the evaluation and benchmark of the mechanistic model is provided in RPP-26676. This engineering notebook provides supportive technical information.

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2.0 EVALUATION OF HOBBS DATA

2.1 HOBBS DATA

A program was conducted in 1986 and 1987 at the SRS to determine the mechanism and rate of OH- depletion through CO₂ absorption, DPST-87-596. The program was conducted for H-area waste tanks. Data from the tests conducted during this program were used to benchmark the mechanistic depletion model. The data were obtained from DPST-87-596 and are summarized in RPP-26676.

Ventilation Flow Rates

$$Q_{srl_data_1} := 430 \text{ cfm}$$

$$Q_{srl_data_2} := 231 \text{ cfm}$$

$$Q_{srl_data_3} := 430 \text{ cfm}$$

$$Q_{srl_data_4} := 266 \text{ cfm}$$

$$Q_{srl_data_5} := 336 \text{ cfm}$$

$$Q_{srl_data_6} := 293 \text{ cfm}$$

$$Q_{srl_data_7} := 264 \text{ cfm}$$

$$Q_{srl_data_8} := 268 \text{ cfm}$$

$$Q_{srl_data_9} := 311 \text{ cfm}$$

$$Q_{srl_data_{10}} := 351 \text{ cfm}$$

OH Concentrations and Absorption Fractions

$$OH_{srl_data_1} := 1 \cdot 10^{-4}$$

$$F_{srl_data_1} := .1$$

$$OH_{srl_data_2} := .062$$

$$F_{srl_data_2} := .4$$

$$OH_{srl_data_3} := .13$$

$$F_{srl_data_3} := .58$$

$$OH_{srl_data_4} := .25$$

$$F_{srl_data_4} := .72$$

$$OH_{srl_data_5} := .40$$

$$F_{srl_data_5} := .70$$

$$OH_{srl_data_6} := .79$$

$$F_{srl_data_6} := .75$$

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$$OH_{srl_data_7} := .89$$

$$F_{srl_data_7} := .79$$

$$OH_{srl_data_8} := .89$$

$$F_{srl_data_8} := .80$$

$$OH_{srl_data_9} := 2.51$$

$$F_{srl_data_9} := .83$$

$$OH_{srl_data_{10}} := 6.31$$

$$F_{srl_data_{10}} := .76$$

$$T_{sup_srl_1} := 92F$$

$$T_{sup_srl_2} := 100F$$

$$T_{sup_srl_3} := 116F$$

$$T_{sup_srl_4} := 91F$$

$$T_{sup_srl_5} := 91F$$

$$T_{sup_srl_6} := 139F$$

$$T_{sup_srl_7} := 109F$$

$$T_{sup_srl_8} := 109F$$

$$T_{sup_srl_9} := 82F$$

$$T_{sup_srl_{10}} := 82F$$

The average temperature difference between the vapor space and supernatant for the non-aging waste Hanford tanks (Section 3.3) is used for the SRS tanks.

$$\Delta T_{ave_hanford} := 2.0F$$

The Hobbs correlation is given by, DPST-87-596,

$$F_{hobbs}(OH) := .165 \cdot \left(14 + \log \left(\frac{OH}{M} \right) \right) - 1.569$$

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$i_{srl_data} := 1..10$

$T_{dome_srl_i_{srl_data}} := T_{sup_srl_i_{srl_data}} - \Delta T_{ave\ hanford}$

$T_{dome_srl_i_{srl_data}} =$

90
98
114
89
89
137
107
107
80
80

F

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2.2 PREDICTION OF ABSORPTION FRACTIONS FOR HOBBS DATA

The mechanistic depletion model is used to predict the CO₂ absorption fraction for the SRS tests.

$$D_{\text{tank}} := 85\text{ft}$$

2.2.1 Tank 42H

$$i_{\text{data}} := 1$$

$$Q_{\text{vent}} := Q_{\text{srl_data } i_{\text{data}}}$$

$$\Delta T_{\text{srl}} := \Delta T_{\text{ave_hanford}}$$

$$\Delta T_{\text{liq}} := 0\text{F}$$

$$T_{\text{sup}} := T_{\text{sup_srl } i_{\text{data}}}$$

$$\text{OH}_{\text{data}} := \text{OH}_{\text{srl_data } i_{\text{data}}} \text{ M}$$

$$D_{\text{liq}} := 4\text{in}$$

$$t_{\text{start}} := 1982\text{yr}$$

$$\Delta t := 1986\text{yr} - t_{\text{start}}$$

$$V_{\text{supsr}} := 600\text{kgal}$$

$$\text{CO3srl} := \frac{20 \frac{\text{mole}}{\text{yr}} \cdot \Delta t}{V_{\text{supsr}}}$$

$$\text{CO3srl} = 3.522 \times 10^{-5} \text{ M}$$

$$\text{CO3}_{\text{bulk}} := \text{CO3srl}$$

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$$Q := Q_{srl_data_i_data}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .07301 \cdot OH_{data}$$

$$CO3_{i_guess} := 3.0173 \cdot CO3_{bulk}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 357 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{srl}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 359.924 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 62.632 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 38.02 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 6.341 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 19.01 \frac{\text{mole}}{\text{yr}}$$

$$F_{srl_calc_i_data} := \frac{OH_{dep}}{2 \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent}}$$

$$F_{srl_calc_i_data} = 2.115 \times 10^{-4}$$

$$OH_{depdata_i_data} := 2 F_{srl_data_i_data} \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent}$$

$$OH_{depcalc_i_data} := OH_{dep}$$

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The depletion rate based upon the Hobbs model is

$$OH_{\text{dephobbs}_{i_{\text{data}}}} := 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}} \cdot F_{\text{hobbs}}(OH_{\text{data}})$$

$$OH_{\text{dep}} = 43.528 \frac{\text{mol}}{\text{yr}}$$

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2.2.2 Tank 48H

$$i_{data} := 2$$

$$Q_{vent} := Q_{srl_data\ i_{data}}$$

$$T_{sup} := T_{sup_srl\ i_{data}}$$

$$OH_{data} := OH_{srl_data\ i_{data}} \text{ M}$$

$$t_{start} := 1983\text{yr}$$

$$\Delta t := 1986\text{yr} - t_{start}$$

$$V_{supsl} := 600\text{kgal}$$

$$CO3_{srl} := \frac{50000 \frac{\text{mole}}{\text{yr}} \cdot \Delta t}{V_{supsl}}$$

$$CO3_{srl} = 0.066 \text{ M}$$

$$CO3_{bulk} := CO3_{srl}$$



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$$Q := Q_{srl_data_i_data}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .0067 \cdot OH_{data}$$

$$CO3_{i_guess} := 3.1 \cdot CO3_{bulk}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 240 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{srl}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 242.185 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 4.161 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 3.619 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.238 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.809 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$F_{srl_calc_i_data} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent}}$$

$$F_{srl_calc_i_data} = 0.327$$

$$OH_{dep_data_i_data} := 2 F_{srl_data_i_data} \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent}$$

$$OH_{dep_calc_i_data} := OH_{dep}$$

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The depletion rate based upon the Hobbs model is

$$OH_{\text{dephobbs}} := 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}} \cdot I_{\text{hobbs}}(OH_{\text{data}})$$

$$OH_{\text{dep}} = 3.619 \times 10^4 \frac{\text{mol}}{\text{yr}}$$

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2.2.3 Tank 42H

$$i_{data} := 3$$

$$Q_{vent} := Q_{srl_data, i_{data}}$$

$$T_{sup} := T_{sup_srl, i_{data}}$$

$$OH_{data} := OH_{srl_data, i_{data}} \text{ M}$$

$$t_{start} := 1982 \text{ yr}$$

$$\Delta t := 1986 \text{ yr} - t_{start}$$

$$V_{supsrl} := 600 \text{ kgal}$$

$$CO3_{srl} := \frac{40000 \frac{\text{mole}}{\text{yr}} \cdot \Delta t}{V_{supsrl}}$$

$$CO3_{srl} = 0.07 \text{ M}$$

$$CO3_{bulk} := CO3_{srl}$$



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$$Q := Q_{srl_data_i_data}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .0047 \cdot OH_{data}$$

$$CO3_{i_guess} := 4.7 \cdot CO3_{bulk}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 220 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{srl}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 222.38 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 8.742 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 7.869 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 2.326 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 3.934 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$F_{srl_calc_i_data} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent}}$$

$$F_{srl_calc_i_data} = 0.382$$

$$OH_{depdata_i_data} := 2 F_{srl_data_i_data} \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent}$$

$$OH_{depcalc_i_data} := OH_{dep}$$

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The depletion rate based upon the Hobbs model is

$$OH_{\text{dephobbs}_{i_{\text{data}}}} = 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}} \cdot F_{\text{hobbs}}(OH_{\text{data}_i})$$

$$OH_{\text{dep}} = 7.869 \times 10^4 \frac{\text{mol}}{\text{yr}}$$

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2.2.4 Tank 48H

$$i_{data} := 4$$

$$Q_{vent} := Q_{srl_data_{i_{data}}}$$

$$T_{sup} := T_{sup_srl_data_{i_{data}}}$$

$$OH_{data} := OH_{srl_data_{i_{data}}} \text{ M}$$

$$t_{start} := 1982 \text{ yr}$$

$$\Delta t := 1986 \text{ yr} - t_{start}$$

$$V_{supsr1_4} := 600 \text{ kgal}$$

$$CO3srl_4 := \frac{100000 \frac{\text{mole}}{\text{yr}} \cdot \Delta t}{V_{supsr1_4}}$$

$$CO3srl_4 = 0.176 \text{ M}$$

$$CO3_{bulk} := CO3srl_4$$



$$Q := Q_{srl_data_i_data}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := 38 \cdot OH_{data}$$

$$CO3_{i_guess} := 4.2 \cdot CO3_{bulk}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 75 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{srl}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 76.667 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.047 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.002 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 5.029 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 5.011 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$F_{srl_calc_i_data} := \frac{OH_{dep}}{2} \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent}$$

$$F_{srl_calc_i_data} = 0.787$$

$$OH_{dep_data_i_data} := 2 F_{srl_data_i_data} \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent}$$

$$OH_{dep_calc_i_data} := OH_{dep}$$

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The depletion rate based upon the Hobbs model is

$$OH_{\text{dephobbs}_{\text{data}}} := 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}} \cdot F_{\text{hobbs}}(OH_{\text{data}})$$

$$OH_{\text{dep}} = 1.002 \times 10^5 \frac{\text{mol}}{\text{yr}}$$

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2.2.5 Tank 49H

$$i_{data} := 5$$

$$Q_{vent} := Q_{srl_data_{i_{data}}}$$

$$T_{sup} := T_{sup_srl_{i_{data}}}$$

$$OH_{data} := OH_{srl_data_{i_{data}}} \text{ M}$$

$$t_{start} := 1982 \text{ yr}$$

$$\Delta t := 1983 \text{ yr} - t_{start}$$

$$V_{sup_{srl_5}} := 600 \text{ kgal}$$

$$CO3_{srl_5} := \frac{120000 \frac{\text{mole}}{\text{yr}} \cdot \Delta t}{V_{sup_{srl_5}}}$$

$$CO3_{srl_5} = 0.053 \text{ M}$$

$$CO3_{bulk} := CO3_{srl_5}$$

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$$Q := Q_{srl_data_i_data}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .55 \cdot OH_{data}$$

$$CO3_{i_guess} := 1.4 \cdot CO3_{bulk}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 90 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{srl}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 90.789 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.216 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.203 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 6.129 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 6.014 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$F_{srl_calc_i_data} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent}}$$

$$F_{srl_calc_i_data} = 0.748$$

$$OH_{depdata_i_data} := 2 F_{srl_data_i_data} \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent}$$

$$OH_{dep_calc_i_data} := OH_{dep}$$

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The depletion rate based upon the Hobbs model is

$$OH_{\text{dephobbs}} := 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}} \cdot F_{\text{hobbs}}(OH_{\text{data}})$$

$$OH_{\text{dep}} = 1.203 \times 10^5 \frac{\text{mol}}{\text{yr}}$$

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2.2.6 Tank 50H

$$i_{data} := 6$$

$$Q_{vent} := Q_{sr1_data} \cdot i_{data}$$

$$T_{sup} := T_{sup_sr1_data}$$

$$OH_{data} := OH_{sr1_data} \cdot M$$

$$t_{start} := 1983 \text{ yr}$$

$$\Delta t := 1986 \text{ yr} - t_{start}$$

$$V_{supsr1_6} := 600 \text{ kgal}$$

$$CO3sr1_6 := \frac{100000 \frac{\text{mole}}{\text{yr}} \cdot \Delta t}{V_{supsr1_6}}$$

$$CO3sr1_6 = 0.132 \text{ M}$$

$$CO3_{bulk} := CO3sr1_6$$



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$$Q := Q_{srl_data_i_data}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .78 \cdot OH_{data}$$

$$CO3_{i_guess} := 6 \cdot CO3_{bulk}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 84 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{srl}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 85.617 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.174 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.069 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 5.893 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 5.345 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$F_{srl_calc_i_data} := \frac{OH_{dep}}{2 \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent}}$$

$$F_{srl_calc_i_data} = 0.762$$

$$OH_{depdata_i_data} := 2 F_{srl_data_i_data} \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent}$$

$$OH_{depcalc_i_data} := OH_{dep}$$

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The depletion rate based upon the Hobbs model is

$$OH_{\text{dephobbs}} := 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}} \cdot R_{\text{hobbs}}(OH_{\text{data}})$$

$$OH_{\text{dep}} = 1.069 \times 10^5 \frac{\text{mol}}{\text{yr}}$$

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2.2.7 Tank 39H

$$i_{data} := 7$$

$$Q_{vent} := Q_{srl_data_i_{data}}$$

$$T_{sup} := T_{sup_srl_i_{data}}$$

$$OH_{data} := OH_{srl_data_i_{data}} \text{ M}$$

$$t_{start} := 1982 \text{ yr}$$

$$\Delta t := 1986 \text{ yr} - t_{start}$$

$$V_{supersrl} := 600 \text{ kgal}$$

$$CO3_{srl7} := \frac{100000 \frac{\text{mole}}{\text{yr}} \cdot \Delta t}{V_{supersrl}}$$

$$CO3_{srl7} = 0.176 \text{ M}$$

$$CO3_{bulk} := CO3_{srl7}$$



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$$Q := Q_{srl_data_i_data}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .83 \cdot OH_{data}$$

$$CO3_{i_guess} := 4 \cdot CO3_{bulk}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 77 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{srl}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 75.972 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.022 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 9.971 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 4.715 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 4.985 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

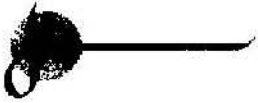
$$F_{srl_calc_i_data} := \frac{OH_{dep}}{2 \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent}}$$

$$F_{srl_calc_i_data} = 0.789$$

$$OH_{depdata_i_data} := 2 \cdot F_{srl_data_i_data} \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent}$$

$$OH_{depcalc_i_data} := OH_{dep}$$

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The depletion rate based upon the Hobbs model is

$$OH_{\text{dephobbs}_{i_{\text{data}}}} := 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}} \cdot F_{\text{hobbs}}(OH_{\text{data}})$$

$$OH_{\text{dep}} = 9.971 \times 10^4 \frac{\text{mol}}{\text{yr}}$$

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2.2.8 Tank 38H

$$i_{data} := 8$$

$$Q_{vent} := Q_{srl_data\ i_{data}}$$

$$T_{sup} := T_{sup_srl\ i_{data}}$$

$$OH_{data} := OH_{srl_data\ i_{data}}\ M$$

$$t_{start} := 1981\text{yr}$$

$$\Delta t := 1986\text{yr} - t_{start}$$

$$V_{supsl_g} := 600\text{kgal}$$

$$CO3srl_g := \frac{100000 \frac{\text{mole}}{\text{yr}} \cdot \Delta t}{V_{supsl_g}}$$

$$CO3srl_g = 0.22\ M$$

$$CO3_{bulk} := CO3srl_g$$

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$$Q := Q_{srl_data_i_data}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .83 \cdot OH_{data}$$

$$CO3_{i_guess} := 4 \cdot CO3_{bulk}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 77.5 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{srl}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 78.395 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.022 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.004 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 5.893 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 5.018 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$F_{srl_calc_i_data} := \frac{OH_{dep}}{2 \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent}}$$

$$F_{srl_calc_i_data} = 0.782$$

$$OH_{dep_data_i_data} := 2 \cdot F_{srl_data_i_data} \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent}$$

$$OH_{dep_calc_i_data} := OH_{dep}$$

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The depletion rate based upon the Hobbs model is

$$OH_{dep_{hobbs, data}} := 2x_{co2_amb} \cdot C_{air} \cdot Q_{vent} \cdot F_{hobbs}(OH_{data})$$

$$OH_{dep} = 1.004 \times 10^5 \frac{\text{mol}}{\text{yr}}$$

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2.2.9 Tank 43H

$$i_{data} := 9$$

$$Q_{vent} := Q_{srl_data_{i_{data}}}$$

$$T_{sup} := T_{sup_srl_{i_{data}}}$$

$$OH_{data} := OH_{srl_data_{i_{data}}} \text{ M}$$

$$t_{start} := 1982\text{yr}$$

$$\Delta t := 1986\text{yr} - t_{start}$$

$$V_{supsl_9} := 600\text{kgal}$$

$$CO3srl_9 := \frac{100000 \frac{\text{mole}}{\text{yr}} \cdot \Delta t}{V_{supsl_9}}$$

$$CO3srl_9 = 0.176 \text{ M}$$

$$CO3_{bulk} := CO3srl_9$$



$$Q := Q_{srl_data_i_data}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := 93 \cdot OH_{data}$$

$$CO3_{i_guess} := 4 \cdot CO3_{bulk}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 83.5 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{srl}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 83.875 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.187 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.142 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 4.715 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 5.71 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

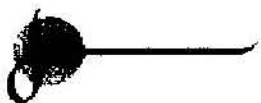
$$F_{srl_calc_i_data} := \frac{OH_{dep}}{2 \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent}}$$

$$F_{srl_calc_i_data} = 0.767$$

$$OH_{dep_data_i_data} := 2 F_{srl_data_i_data} \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent}$$

$$OH_{dep_calc_i_data} := OH_{dep}$$

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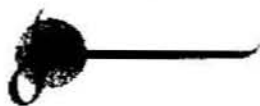
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The depletion rate based upon the Hobbs model is

$$OH_{\text{dephobbs}} := 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}} \cdot F_{\text{hobbs}}(OH_{\text{data}})$$

$$OH_{\text{dep}} = 1.142 \times 10^5 \frac{\text{mol}}{\text{yr}}$$

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2.2.10 Tank 41H

$$i_{data} := 10$$

$$Q_{vent} := Q_{srl_data, i_{data}}$$

$$T_{sup} := T_{sup_srl_data}$$

$$OH_{data} := OH_{srl_data, i_{data}} \text{ M}$$

$$t_{start} := 1982\text{yr}$$

$$\Delta t := 1986\text{yr} - t_{start}$$

$$V_{supsl_{10}} := 600\text{kgal}$$

$$CO3srl_{10} := \frac{120000 \frac{\text{mole}}{\text{yr}} \cdot \Delta t}{V_{supsl_{10}}}$$

$$CO3srl_{10} = 0.211 \text{ M}$$

$$CO3_{bulk} := CO3srl_{10}$$



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$$Q := Q_{srl_data_i_data}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .97 \cdot OH_{data}$$

$$CO3_{i_guess} := 4 \cdot CO3_{bulk}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 91.5 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{srl}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 91.902 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.279 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.251 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 5.658 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 6.257 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

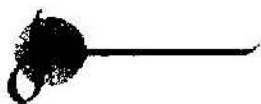
$$F_{srl_calc_i_data} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent}}$$

$$F_{srl_calc_i_data} = 0.745$$

$$OH_{depdata_i_data} := 2 F_{srl_data_i_data} \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent}$$

$$OH_{depcale_i_data} := OH_{dep}$$

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$$\text{OH}_{\text{dep}} = 1.251 \times 10^5 \frac{\text{mol}}{\text{yr}}$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dephobbs, data}} := 2x_{\text{co2, amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}} \cdot F_{\text{hobbs}}(\text{OH}_{\text{data}})$$

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3.0 EVALUATION OF HANFORD WASTE TANKS

3.1 CALCULATION OF OH DEPLETION RATES

The mechanistic depletion model is applied to Hanford site data in the following section. The OH sample data used for the evaluation is summarized in RPP-26676. The temperature Data were obtained from TWINS 2005, *Tank Waste Information Network System*. Waste volume were obtained from TWINS 2005 and HNF-EP-0182, *Waste Tank Summary Report for Month Ending July 31, 2007, Rev 220*.

3.1.1 Tank AN-104

The OH and waste volume data is shown in Figure 4-1. A summary of the hydroxide data is provided in RPP-26676. The average waste volume during the period of evaluation is

$$V_{\text{waste_an4}} := 1052000\text{gal}$$

The sludge volume is

$$V_{\text{solids_an4}} := 445000\text{gal}$$

The supernatant volume is

$$V_{\text{sup}_1} := V_{\text{waste_an4}} - V_{\text{solids_an4}}$$

$$V_{\text{sup}_1} = 607\text{ kgal}$$

$$z_{\text{solids}} := \frac{V_{\text{solids_an4}}}{A_{\text{tank}}}$$

$$z_{\text{solids}} = 161.584\text{ in}$$

The AN-104 Waste temperature profile is shown in Figure 4-2, TWINS 2005. The TC 17 and TC18 temperatures are shown in Figure 4-3. The average dome and supernatant temperatures based upon these thermal couples are

$$T_{\text{sup_an4}} := 91.6\text{F}$$

$$T_{\text{dome_an4}} := 83.2\text{F}$$

$$\Delta T_{\text{hanford}_1} := T_{\text{sup_an4}} - T_{\text{dome_an4}}$$

$$\Delta T_{\text{hanford}_1} = 8.4\text{F}$$

Figure 4-4 shows representative supernatant and dome temperatures for Tank AN-103 which has a similar heat load and ventilation flow. The average temperature difference is

$$\Delta T_{\text{an3}} := 2.285\text{F}$$

$$\Delta T_{\text{hanford}_1} := \Delta T_{\text{an3}}$$

This is similar to tank AN-101 and is more reasonable for a supernatant without a crust. The Tank AN-104 temperature difference is an indication of a crust at the supernatant surface. Figure 4-2 shows the elevation of the top TC which is not in the crust since it has nearly the same temperature as the lower supernatant TC's. The difference between this elevation and the waste level is the maximum crust thickness.

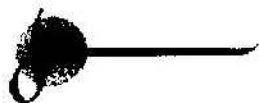
$$L_{\text{crust_an4}} := 20\text{in}$$

The crust porosity is assumed to be

$$E := .02$$

This is an empirical value applied to all crust tanks.

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$$T_{\text{supernate}_1} := T_{\text{dome_an4}} + \Delta T_{\text{hanford}_1}$$

$$T_{\text{sup_an4}} = 91.6 \text{ F}$$

The initial OH concentration is

$$\text{OH}_{\text{hanford_data}_1} := \frac{4.05\text{M} + 3.84\text{M}}{2}$$

$$\text{OH}_{\text{hanford_data}_1} = 3.945 \text{ M}$$

The primary tank ventilation system flow rate is (Section 5.10.1),

$$Q_{\text{vent}_1} := 132 \text{ cfm}$$

$$\text{CO3}_1 := \frac{20000 \frac{\text{mole}}{\text{yr}} \cdot 10 \text{ yr}}{V_{\text{sup}_1}}$$

$$\text{CO3}_1 = 0.087 \text{ M}$$

$$i_{\text{data}} := 11$$

$$ii := 1$$

$$D_{\text{tank}} := 75 \text{ ft}$$



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$$Q := Q_{vent_ii}$$

$$T_{sup} := T_{supernate_ii}$$

$$OH_{data} := OH_{hanford_data_ii}$$

$$CO3_{bulk} := CO3_{ii}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .000556 \cdot OH_{data}$$

$$CO3_{i_guess} := 90 - CO3_{bulk}$$

$$CO3_{i_guess} = 7.834 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, L_{crust_an4}, E \cdot A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, L_{crust_an4}, E \cdot A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, L_{crust_an4}, E \cdot A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 299 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{hanford_i}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

$$OH_{dep} = 1.059 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q \cdot \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 299.69 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.066 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.059 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 2.765 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 5.293 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

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$$OH_{dep_an4} := OH_{dep}$$

OH Depletion Rate

The OH depletion rate is twice the CO_2 rate and given by

$$OH_{dep_hanford_ogden_1} := \frac{OH_{dep}}{V_{sup_1}}$$

$$OH_{dep_hanford_ogden_1} = 4.607 \times 10^{-3} \frac{M}{yr}$$

The maximum OH depletion rate is

$$OH_{dep_max} := \frac{2x_{co2_amb} \cdot C_{air} \cdot Q_{vent_1}}{V_{sup_1}}$$

$$OH_{dep_max} = 0.028 \frac{M}{yr}$$

The depletion rate based upon the Hobbs model is

$$OH_{dep_hanford_hobbs_1} := \frac{2x_{co2_amb} \cdot C_{air} \cdot Q_{vent_1} \cdot F_{hobbs}(OH_{hanford_data_1})}{V_{sup_1}}$$

$$OH_{dep_hanford_hobbs_1} = 0.023 \frac{M}{yr}$$

The caustic depletion data is shown in the figure below. The depletion rate is

$$OH_{dep_hanford_data_1} := 2.34 \cdot 10^{-5} \frac{M}{day}$$

$$OH_{dep_hanford_data_1} = 8.547 \times 10^{-3} \frac{M}{yr}$$

The carbon dioxide absorption rate based on the Hanford OH concentration data and mechanistic model is

$$F_{hanford_data_1} := \frac{\frac{OH_{dep_hanford_data_1}}{2} \cdot V_{sup_1}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent_1}}$$

$$F_{hanford_data_1} = 0.311$$

$$F_{hanford_ogden_1} := \frac{\frac{OH_{dep_hanford_ogden_1}}{2} \cdot V_{sup_1}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent_1}}$$

$$F_{hanford_ogden_1} = 0.168$$

$$OH_{depcalc_data} := OH_{dep}$$

$$OH_{depdata_data} := OH_{dep_hanford_data_1} \cdot V_{sup_1}$$

$$OH_{dep_an4} := OH_{dep}$$



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The depletion rate based upon the Hobbs model is

$$OH_{dephobbs_data} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

Figure 3-1. AN-104 Caustic Depletion Data.

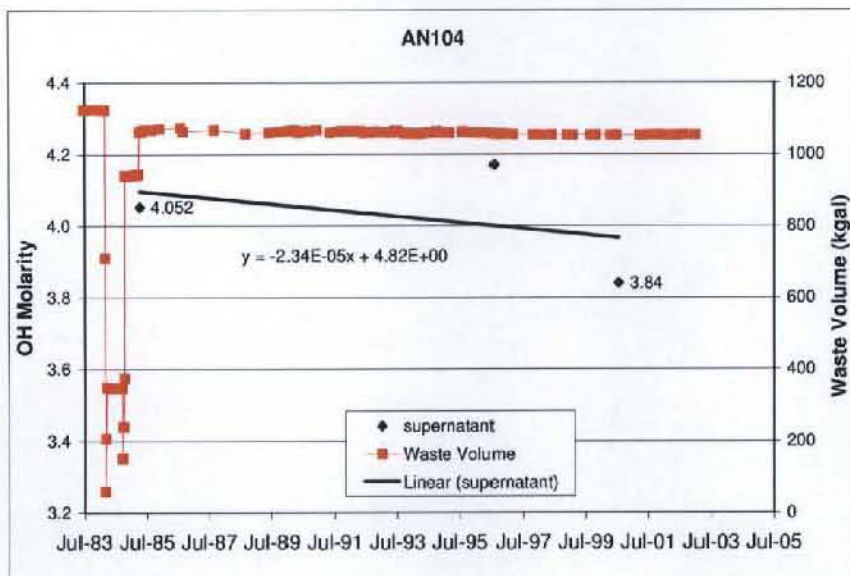
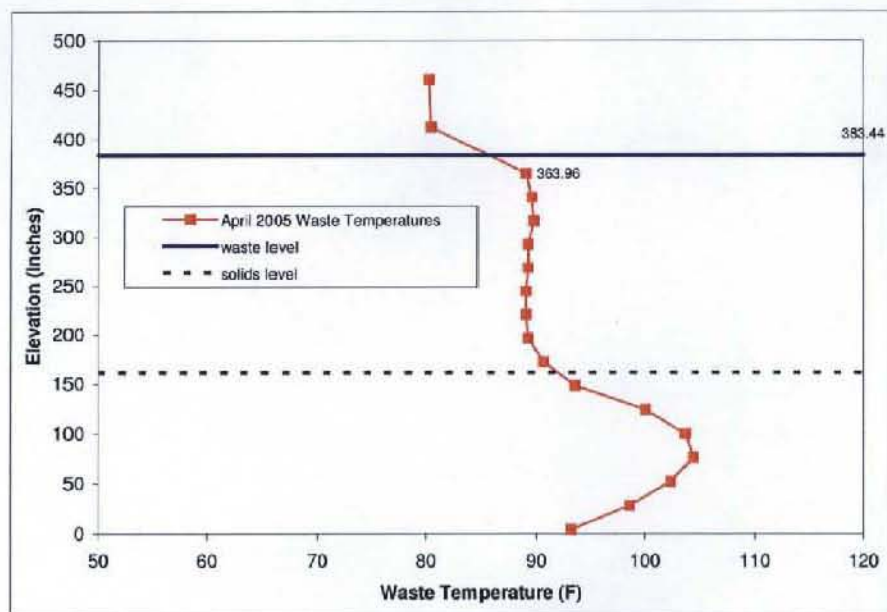


Figure 3-2. AN-104 Waste Temperature Profile.

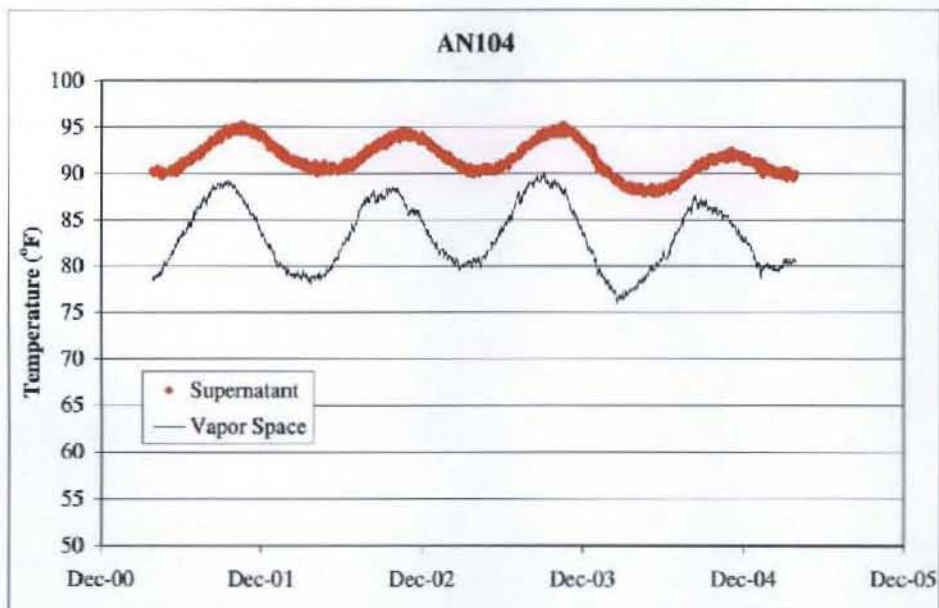
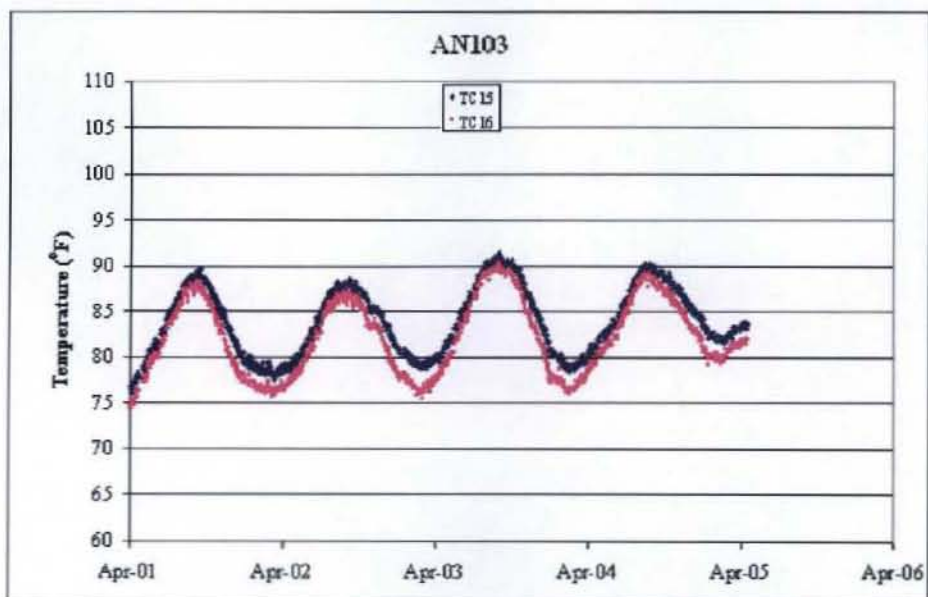




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Figure 3-3. AN-104 Waste Temperatures.**Figure 3-4. AN-103 Waste Temperatures.**

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3.1.2 Tank AN-105

The OH and waste volume data is shown in Figure 3-5, RPP-26676. The average waste volume for the evaluation period is

$$V_{\text{waste_an5}} := 1126000 \text{ gal}$$

The solids volume, HNF-EP-0182 is

$$V_{\text{solids_an5}} := 538000 \text{ gal}$$

The supernatant volume is then

$$V_{\text{sup}_2} := V_{\text{waste_an5}} - V_{\text{solids_an5}}$$

$$V_{\text{sup}_2} = 588 \text{ kgal}$$

The annual supernatant and dome temperatures are shown in Figure 3-6, TWINS 2005. The large temperature difference is the result of a crust floating on the supernatant. The average temperature difference (dome/supernatant) from Tanks AN-103 will be used for AN-105. This is justified since the AN tanks have similar ventilation flows and heat loads. The average dome temperature from Figure 3-4 is

$$T_{\text{dome_an5}} := 81.6 \text{ F}$$

$$T_{\text{supernate}_2} := 90 \text{ F}$$

$$\Delta T_{\text{hanford}_2} := \Delta T_{\text{an3}}$$

Figure 3-7 shows the elevation of the top Riser 17 TC in the supernatant. The difference between this elevation and the waste level is the maximum crust thickness.

$$L_{\text{crust_an5}} := 19 \text{ in}$$

The primary tank ventilation flow rate is for the time period shown in Figure 3-5 is given in Section 5.10.1.

$$Q_{\text{vent}_2} := 132 \text{ cfm}$$

The initial OH concentration From Figure 3-5 is

$$\text{OH}_{\text{hanford_data}_2} := \frac{3.93 \text{ M} + 3.51 \text{ M}}{2}$$

$$\text{OH}_{\text{hanford_data}_2} = 3.72 \text{ M}$$

$$\text{CO}_2 := \frac{4000 \frac{\text{mole}}{\text{yr}} \cdot 10 \text{ yr}}{V_{\text{sup}_2}}$$

$$\text{CO}_2 = 0.018 \text{ M}$$

$$ii := 2$$



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$$Q := Q_{vent_ii}$$

$$T_{sup} := T_{supernat_ii}$$

$$OH_{data} := OH_{hanford_data_ii}$$

$$CO3_{bulk} := CO3_{ii}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .00067 \cdot OH_{data}$$

$$CO3_{i_guess} := 560 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 10.064 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, L_{crust_an5}, E \cdot A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, L_{crust_an5}, E \cdot A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, L_{crust_an5}, E \cdot A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 298 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{hanford_2}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

$$OH_{dep} = 1.114 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 296.562 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.058 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.114 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 3.774 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 5.568 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

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$$OH_{dep_ans} := OH_{dep}$$

OH Depletion Rate

The OH depletion rate is twice the CO_2 rate and given by

$$OH_{dep_hanford_ogden_ii} := \frac{OH_{dep}}{V_{sup_ii}}$$

$$OH_{dep_hanford_ogden_ii} = 5.003 \times 10^{-3} \frac{M}{yr}$$

The maximum OH depletion rate is

$$OH_{dep_max} := \frac{2x_{co2_amb} \cdot C_{air} \cdot Q_{vent_ii}}{V_{sup_ii}}$$

$$OH_{dep_max} = 0.028 \frac{M}{yr}$$

The depletion rate based upon the Hobbs model is

$$OH_{dep_hanford_hobbs_ii} := \frac{2x_{co2_amb} \cdot C_{air} \cdot Q_{vent_ii} \cdot F_{hobbs}(OH_{hanford_data_ii})}{V_{sup_ii}}$$

$$OH_{dep_hanford_hobbs_ii} = 0.024 \frac{M}{yr}$$

The caustic depletion data is shown in the figure below. The depletion rate is

$$OH_{dep_hanford_data_ii} := 7.57 \cdot 10^{-5} \frac{M}{day}$$

$$OH_{dep_hanford_data_ii} = 0.028 \frac{M}{yr}$$

$$OH_{dep_hanford_data_ii} := OH_{dep_max}$$

$$F_{hanford_data_ii} := \frac{\frac{OH_{dep_hanford_data_ii}}{2} \cdot V_{sup_ii}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent_ii}}$$

$$F_{hanford_data_ii} = 1$$

$$F_{hanford_ogden_ii} := \frac{\frac{OH_{dep_hanford_ogden_ii}}{2} \cdot V_{sup_ii}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent_ii}}$$

$$F_{hanford_ogden_ii} = 0.176$$



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$$i_{data} := 10 + ii$$

$$OH_{dep_{calc}, i_{data}} := OH_{dep}$$

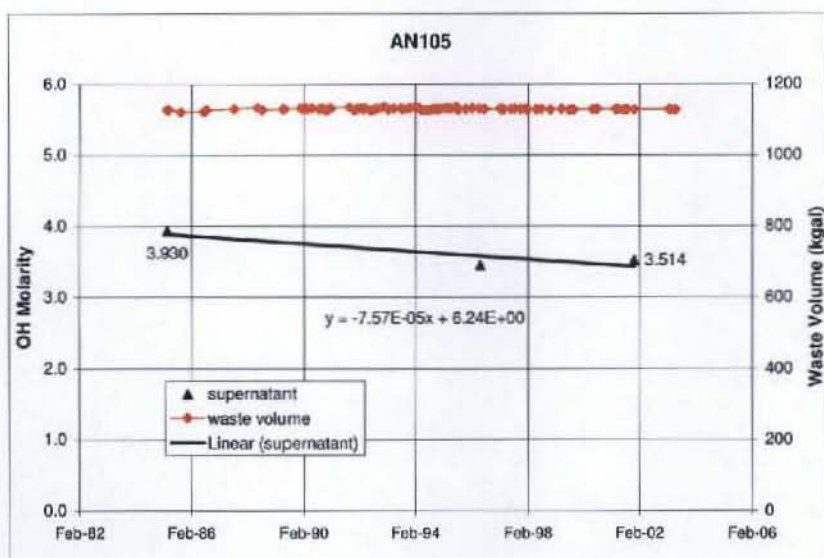
$$OH_{dep_{data}, i_{data}} := OH_{dep_hanford_data, ii} \cdot V_{sup, ii}$$

$$OH_{dep_{ans}} := OH_{dep}$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs, i_{data}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

Figure 3-5. AN-105 Caustic Depletion Data.

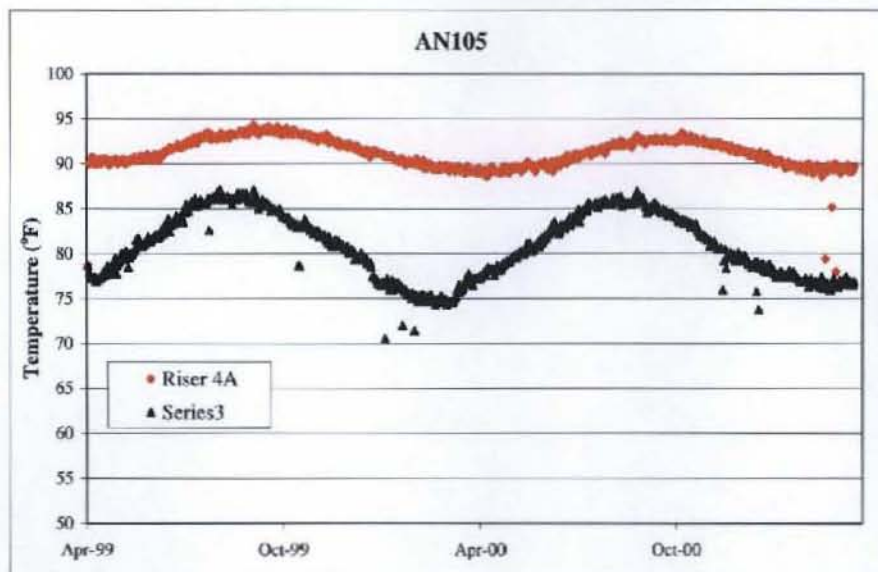




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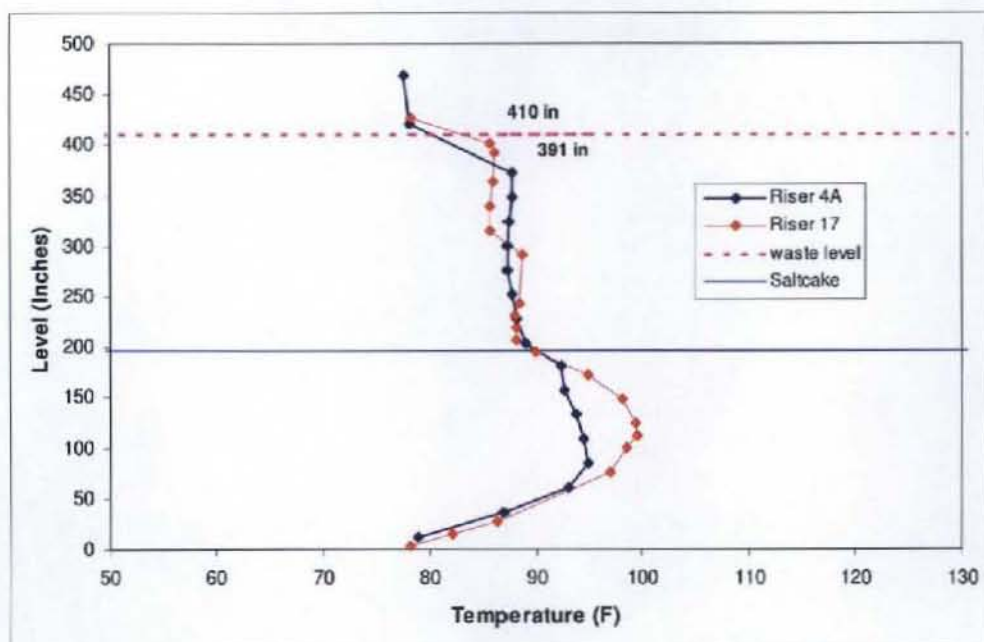
Figure 3-6. AN-105 Waste Temperatures.



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Figure 3-7. AN-105 Waste Temperature Profile.

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3.1.3 Tank AP-101

The OH and waste volume data is shown in Figure 3-8, RPP-26676. The initial waste volume (at the time of the 2000 sample data) is

$$V_{\text{waste_ap1}} := 1113 \text{ kgal}$$

The final waste volume is

$$V_{\text{waste_ap1_final}} := 403.4 \text{ in} \cdot A_{\text{rank}}$$

The sludge volume, HNF-EP-0182, is

$$V_{\text{solids_ap1}} := 0 \text{ gal}$$

The average supernatant volume is then

$$V_{\text{sup}_3} := \frac{V_{\text{waste_ap1}} + V_{\text{waste_ap1_final}}}{2}$$

$$V_{\text{sup}_3} = 1.112 \times 10^3 \text{ kgal}$$

The annual supernatant and dome temperatures are shown in Figure 3-9, TWINS 2005. The average supernatant is

$$T_{\text{sup_ap1}} := 66 \cdot \text{F}$$

The average temperature difference

$$\Delta T_{\text{hanford}_3} := 0.01 \text{ F}$$

The measured 241-AP Tanks Exhauster 296-A-40 flow rates (2E-99-01324, 2E9901821, 2E-99-02471, 2E-99-02695, 2E-00-477, 2E-00-1319, 241- AP Tank Stack Air Flow) from June 24, 1999 to July 24, 2000 are shown in Figure 2-3. The average stack flow rate for this period is 887 Acfm. The ventilation flow rate for the individual tanks is not known. The ventilation flow is assumed to be equal for the eight 241-AP Tanks. Thus, ventilation flow rate used for the hydroxide depletion evaluation is 111 Acfm.

The primary tank ventilation flow rate is, RPP-29806

$$Q_{\text{vent}_3} := 111 \text{ cfm}$$

The initial OH concentration shown in Figure 3-8 is

$$\text{OH}_{\text{hanford_data}_3} := \frac{2.43 \text{ M} + 2.34 \text{ M}}{2}$$

$$\text{OH}_{\text{hanford_data}_3} = 2.385 \text{ M}$$

$$\text{CO}_3 := \frac{30000 \frac{\text{mole}}{\text{yr}} \cdot 15 \text{ yr}}{V_{\text{sup}_3}}$$

$$\text{ii} := 3$$



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$$Q := Q_{vent_{ii}}$$

$$T_{sup} := T_{sup_ap1}$$

$$OH_{data} := OH_{hanford_data_{ii}}$$

$$CO3_{bulk} := CO3_{ii}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .979 \cdot OH_{data}$$

$$CO3_{i_guess} := 2.5 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.267 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 135 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{hanford}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

$$OH_{dep} = 3.322 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 134.928 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.384 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 3.322 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.431 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.661 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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OH Depletion Rate

The OH depletion rate is twice the CO₂ rate and given by

$$OH_{dep_hanford_ogden_u} := \frac{OH_{dep}}{V_{sup_u}}$$

$$OH_{dep_hanford_ogden_u} = 7.892 \times 10^{-3} \frac{M}{yr}$$

The maximum OH depletion rate is

$$OH_{dep_max} := \frac{2x_{co2_amb} \cdot C_{air} \cdot Q_{vent_u}}{V_{sup_u}}$$

$$OH_{dep_max} = 0.013 \frac{M}{yr}$$

The depletion rate based upon the Hobbs model is

$$OH_{dep_hanford_hobbs_u} := \frac{2x_{co2_amb} \cdot C_{air} \cdot Q_{vent_u} \cdot F_{hobbs}(OH_{hanford_data_u})}{V_{sup_u}}$$

$$OH_{dep_hanford_hobbs_u} = 0.01 \frac{M}{yr}$$

The caustic depletion data is shown in the figure below. The depletion rate is

$$OH_{dep_hanford_data_u} := 5.94 \cdot 10^{-5} \frac{M}{day}$$

$$OH_{dep_hanford_data_u} = 0.022 \frac{M}{yr}$$

This exceeds the maximum depletion rate for the assumed ventilation flow rate. The data value will be set the the maximum value for comparison with the calculation.

$$OH_{dep_hanford_data_u} := OH_{dep_max}$$

The carbon dioxide absorption rate based on the Hanford OH concentration data is

$$F_{hanford_data_u} := \frac{\frac{OH_{dep_hanford_data_u}}{2} \cdot V_{sup_u}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent_u}}$$

$$F_{hanford_data_u} = 1$$



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$$F_{\text{hanford_ogden}_{ii}} := \frac{\text{OH}_{\text{dep_hanford_ogden}_{ii}}}{2} \cdot V_{\text{sup}_{ii}} \cdot \frac{1}{x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_{ii}}}$$

$$F_{\text{hanford_ogden}_{ii}} = 0.625$$

$$i_{\text{data}} := 10 + ii$$

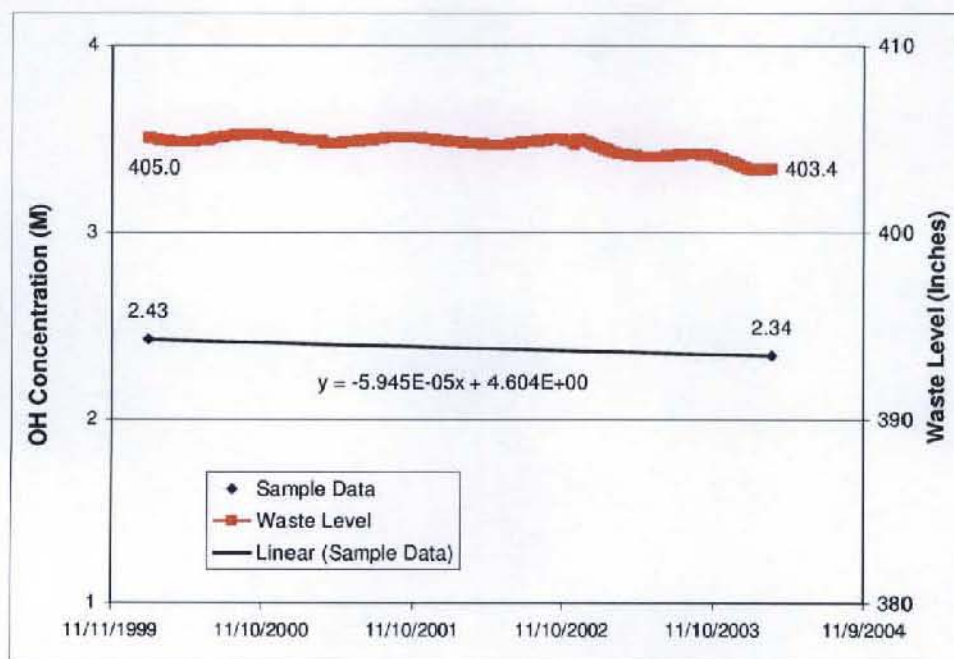
$$\text{OH}_{\text{depcale}_{i_{\text{data}}}} := \text{OH}_{\text{dep}}$$

$$\text{OH}_{\text{depdata}_{i_{\text{data}}}} := \text{OH}_{\text{dep_hanford_data}_{ii}} \cdot V_{\text{sup}_{ii}}$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dephobbs}_{i_{\text{data}}}} := 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q \cdot F_{\text{hobbs}}(\text{OH}_{\text{data}})$$

Figure 3-8. AP-101 Caustic Depletion Data.

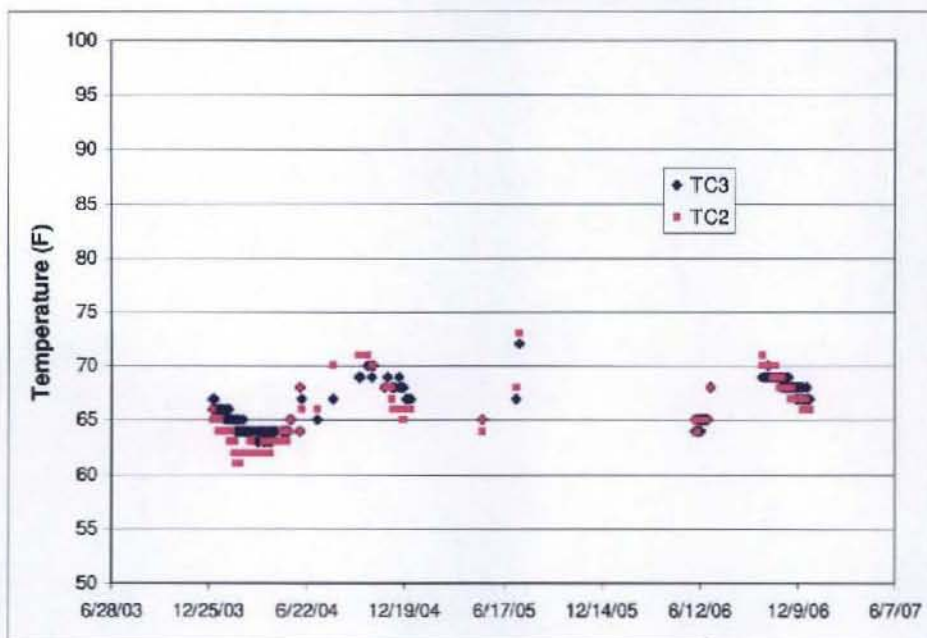




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Figure 3-9. AP-101 Waste Temperatures.

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3.1.4 Tank AP-103

The OH and waste volume data is shown in Figure 3-9, RPP-26676. The average waste volume is

$$V_{\text{waste_ap3}} := 282000 \text{ gal}$$

The sludge volume, HNF-EP-0182, is

$$V_{\text{solids_ap3}} := 0 \text{ gal}$$

The supernatant volume is then

$$V_{\text{sup}_4} := V_{\text{waste_ap3}} - V_{\text{solids_ap3}}$$

$$V_{\text{sup}_4} = 282 \text{ kgal}$$

The annual supernatant and dome temperatures are shown in Figure 3-10, TWINS 2005. The average supernatant is

$$T_{\text{sup_ap3}} := 66 \text{ }^{\circ}\text{F}$$

$$\Delta T_{\text{hanford}_4} := 0.01 \text{ }^{\circ}\text{F}$$

$$Q_{\text{vent}_4} := Q_{\text{vent}_3}$$

The initial OH concentration shown in Figure 3-10 is

$$\text{OH}_{\text{hanford_data}_4} := \frac{0.56 \text{ M} + .49 \text{ M}}{2}$$

$$\text{OH}_{\text{hanford_data}_4} = 0.525 \text{ M}$$

$$\text{CO}_{3_4} := \frac{20000 \frac{\text{mole}}{\text{yr}} \cdot 15 \text{ yr}}{V_{\text{sup}_4}}$$

$$\text{ii} := 4$$



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$$Q := Q_{vent_i}$$

$$T_{sup} := T_{sup_up3}$$

$$OH_{data} := OH_{hanford_data_i}$$

$$CO3_{bulk} := CO3_{ii}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .905 \cdot OH_{data}$$

$$CO3_{i_guess} := 1.56 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.438 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 135 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{hanford_i}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

$$OH_{dep} = 3.322 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 134.928 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.37 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 3.322 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.404 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.661 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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OH Depletion Rate

The OH depletion rate is twice the CO_2 rate and given by

$$\text{OH}_{\text{dep_hanford_ogden}_i} := \frac{\text{OH}_{\text{dep}}}{V_{\text{sup}_i}}$$

$$\text{OH}_{\text{dep_hanford_ogden}_i} = 0.031 \frac{\text{M}}{\text{yr}}$$

The maximum OH depletion rate is

$$\text{OH}_{\text{dep_max}} := \frac{2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i}}{V_{\text{sup}_i}}$$

$$\text{OH}_{\text{dep_max}} = 0.05 \frac{\text{M}}{\text{yr}}$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dep_hanford_hobbs}_i} := \frac{2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i} \cdot F_{\text{hobbs}}(\text{OH}_{\text{hanford_data}_i})}{V_{\text{sup}_i}}$$

$$\text{OH}_{\text{dep_hanford_hobbs}_i} = 0.035 \frac{\text{M}}{\text{yr}}$$

The caustic depletion data is shown in the figure below. The depletion rate is

$$\text{OH}_{\text{dep_hanford_data}_i} := 5.585 \cdot 10^{-5} \frac{\text{M}}{\text{day}}$$

$$\text{OH}_{\text{dep_hanford_data}_i} = 0.02 \frac{\text{M}}{\text{yr}}$$

The carbon dioxide absorption rate based on the Hanford OH concentration data is

$$F_{\text{hanford_data}_i} := \frac{\frac{\text{OH}_{\text{dep_hanford_data}_i}}{2} \cdot V_{\text{sup}_i}}{x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i}}$$

$$F_{\text{hanford_data}_i} = 0.41$$

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$$F_{\text{hanford_ogden}_i} := \frac{\frac{\text{OH}_{\text{dep_hanford_ogden}_i}}{2} \cdot V_{\text{sup}_i}}{x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i}}$$

$$F_{\text{hanford_ogden}_i} = 0.625$$

$$i_{\text{data}} := 10 + ii$$

$$\text{OH}_{\text{depcalc}_i} := \text{OH}_{\text{dep}}$$

$$\text{OH}_{\text{depdata}_i} := \text{OH}_{\text{dep_hanford_data}_i} \cdot V_{\text{sup}_i}$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dephobbs}_i} := 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q \cdot F_{\text{hobbs}}(\text{OH}_{\text{data}_i})$$



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Figure 3-10. AP-103 Caustic Depletion Data.

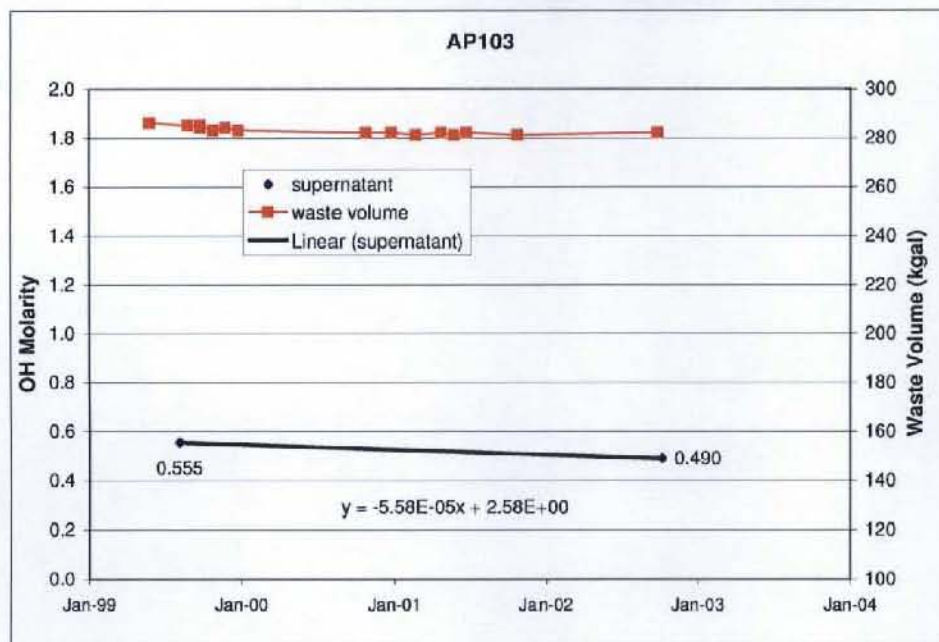
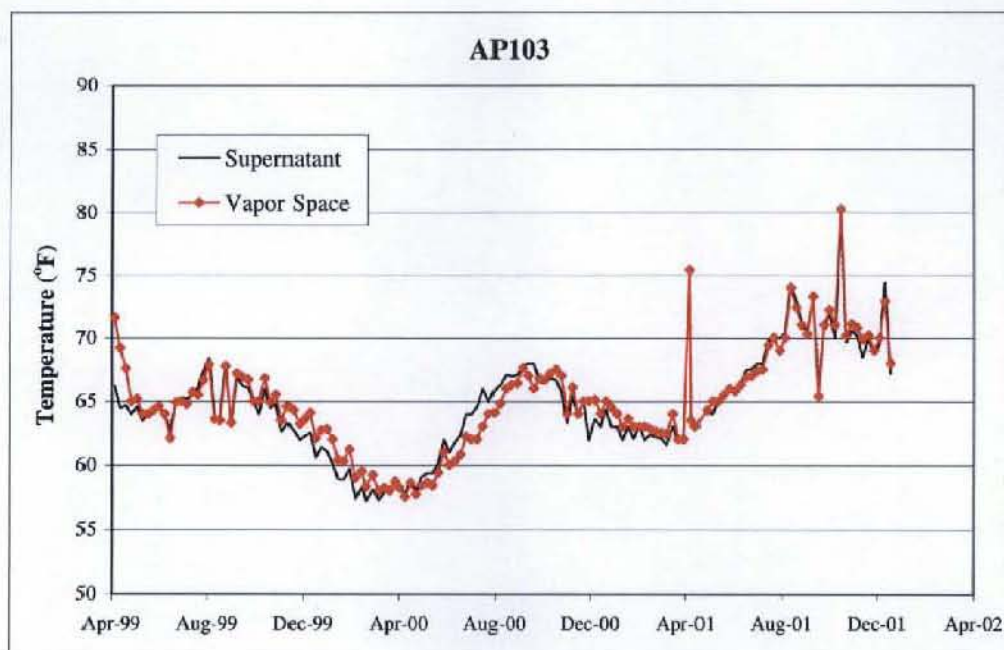


Figure 3-11. AP-103 Waste Temperatures.



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3.1.5 Tank AW-103

The OH and waste volume data is shown in Figure 3-12. The average waste volume is

$$V_{\text{waste_aw3}} := 399 \text{ in} \cdot A_{\text{tank}}$$

$$V_{\text{waste_aw3}} = 1.099 \times 10^3 \text{ kgal}$$

The sludge volume, HNF-EP-0182, is

$$V_{\text{solids_aw3}} := 273 \text{ kgal} + 40 \text{ kgal}$$

The supernatant volume is then

$$V_{\text{sup}_5} := V_{\text{waste_aw3}} - V_{\text{solids_aw3}}$$

$$V_{\text{sup}_5} = 785.843 \text{ kgal}$$

The annual supernatant and dome temperatures are shown in Figure 3-13, TWINS 2005. The average supernatant is

$$T_{\text{sup_aw3}} := 65 \cdot \text{F}$$

$$\Delta T_{\text{hanford}_5} := 0.05 \text{ F}$$

The waste temperature profile is shown in Figure 3-14. There is no indication of a supernatant crust.

The primary tank ventilation flow rate is (Table 5-1)

$$Q_{\text{vent}_5} := 139 \text{ cfm}$$

$$Q_{\text{vent}_5} = 139 \text{ cfm}$$

The initial OH concentration shown in Figure 3-12 is

$$\text{OH}_{\text{hanford_data}_5} := \frac{0.826 \text{ M} + .765 \text{ M}}{2}$$

$$\text{OH}_{\text{hanford_data}_5} = 0.796 \text{ M}$$

$$\text{CO}_2 := \frac{20000 \frac{\text{mole}}{\text{yr}} \cdot 20 \text{ yr}}{V_{\text{sup}_5}}$$

$$ii := 5$$



$$Q := Q_{vent_i}$$

$$T_{sup} := T_{sup_aw3}$$

$$OH_{data} := OH_{hanford_data_a}$$

$$CO3_{bulk} := CO3_{ii}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .92 \cdot OH_{data}$$

$$CO3_{i_guess} := 2.9 \cdot CO3_{bulk}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 110 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{hanford_ii}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 108.685 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 4.3 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 4.645 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 2.28 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 2.323 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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OH Depletion Rate

The OH depletion rate is twice the CO_2 rate and given by

$$\text{OH}_{\text{dep_hanford_ogden}_u} := \frac{\text{OH}_{\text{dep}}}{V_{\text{sup}_u}}$$

$$\text{OH}_{\text{dep_hanford_ogden}_u} = 0.016 \frac{\text{M}}{\text{yr}}$$

The maximum OH depletion rate is

$$\text{OH}_{\text{dep_max}} := \frac{2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_u}}{V_{\text{sup}_d}}$$

$$\text{OH}_{\text{dep_max}} = 0.022 \frac{\text{M}}{\text{yr}}$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dep_hanford_hobbs}_u} := \frac{2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_u} \cdot F_{\text{hobbs}}(\text{OH}_{\text{hanford_data}_u})}{V_{\text{sup}_u}}$$

$$\text{OH}_{\text{dep_hanford_hobbs}_u} = 0.016 \frac{\text{M}}{\text{yr}}$$

The caustic depletion data is shown in the figure below. The depletion rate is

$$\text{OH}_{\text{dep_hanford_data}_u} := 3.69 \cdot 10^{-5} \frac{\text{M}}{\text{day}}$$

$$\text{OH}_{\text{dep_hanford_data}_u} = 0.013 \frac{\text{M}}{\text{yr}}$$

The carbon dioxide absorption rate based on the Hanford OH concentration data is

$$F_{\text{hanford_data}_u} := \frac{\frac{\text{OH}_{\text{dep_hanford_data}_u}}{2} \cdot V_{\text{sup}_u}}{x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_u}}$$

$$F_{\text{hanford_data}_u} = 0.603$$

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$$F_{\text{hanford_ogden}_i} := \frac{\text{OH}_{\text{dep_hanford_ogden}_{ii}} \cdot V_{\text{sup}_i}}{2 \cdot x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i}}$$

$$F_{\text{hanford_ogden}_i} = 0.698$$

$$i_{\text{data}} := 10 + ii$$

$$\text{OH}_{\text{dep_calc}_{i_{\text{data}}}} := \text{OH}_{\text{dep}}$$

$$\text{OH}_{\text{dep_data}_{i_{\text{data}}}} := \text{OH}_{\text{dep_hanford_data}_i} \cdot V_{\text{sup}_{ii}}$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dep_hobbs}_{i_{\text{data}}}} := 2 \cdot x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q \cdot F_{\text{hobbs}}(\text{OH}_{\text{data}})$$

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Figure 3-12. AW-103 Caustic Depletion Data.

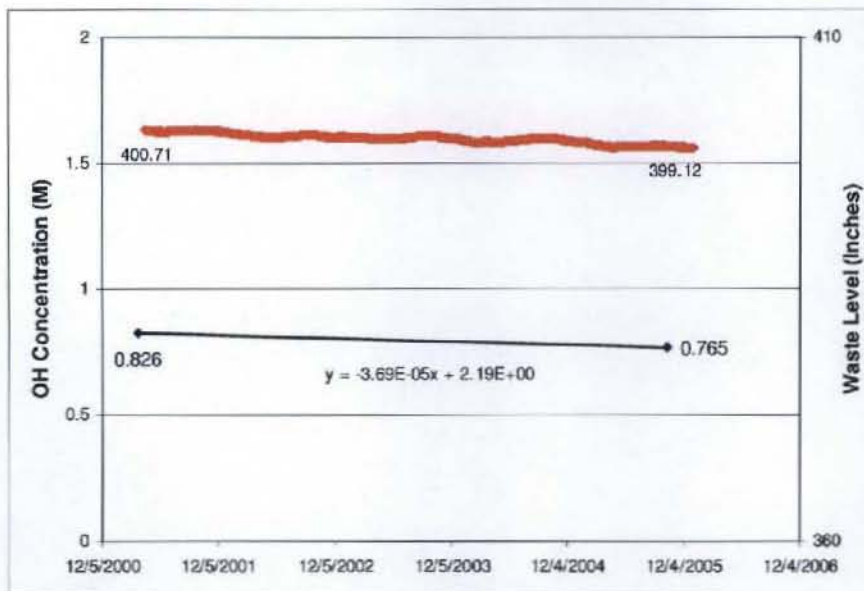
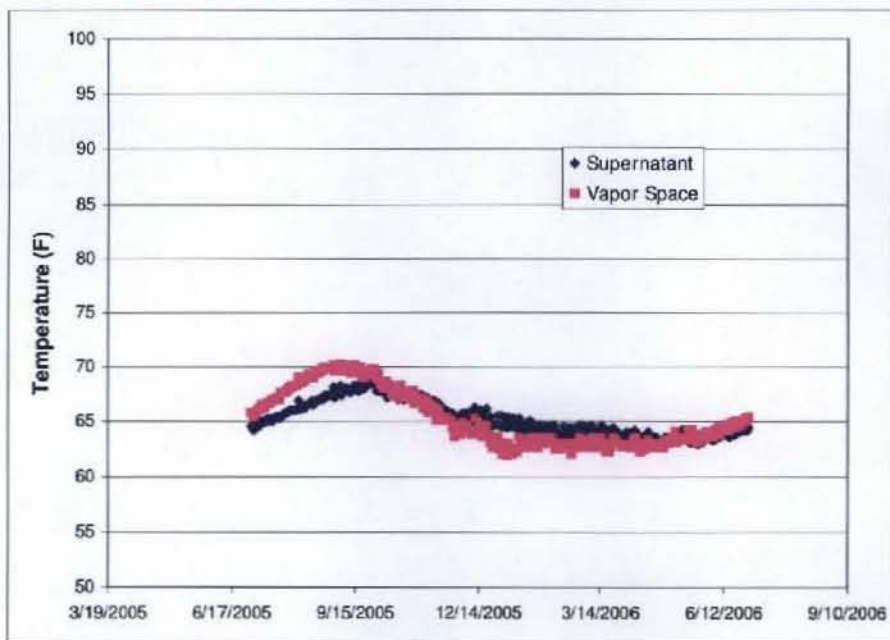


Figure 3-13. AW-103 Waste Temperatures.



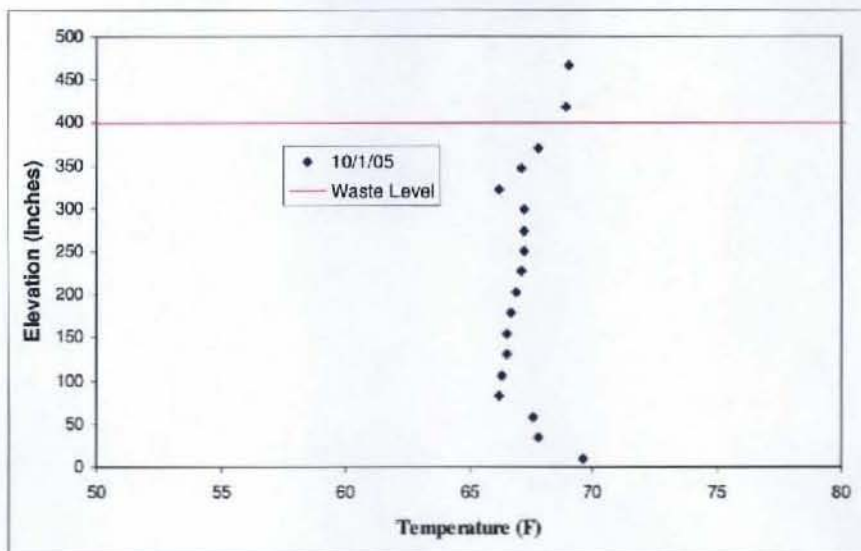


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Figure 3-14. AW-103 Waste Temperature Profile.



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3.1.6 Tank AW-105

The OH and waste volume data is shown in Figure 3-15. The average waste volume is

$$V_{\text{waste_aw5}} := \frac{153.6\text{in} + 152\text{in}}{2} A_{\text{tank}}$$

$$V_{\text{waste_aw5}} = 420.81 \text{ kgal}$$

The sludge volume, HNF-EP-0182, is

$$V_{\text{solids_aw5}} := 263 \text{ kgal}$$

The supernatant volume is then

$$V_{\text{sup}_6} := V_{\text{waste_aw5}} - V_{\text{solids_aw5}}$$

$$V_{\text{sup}_6} = 157.81 \text{ kgal}$$

The annual supernatant and dome temperatures are shown in Figure 3-16, TWINS 2005. The average supernatant is

$$T_{\text{sup_aw5}} := 61.^\circ\text{F}$$

$$\Delta T_{\text{hanford}_6} := -0.01^\circ\text{F}$$

The waste temperature profile is shown in Figure 3-17. There is no indication of a supernatant crust.

The primary tank ventilation flow rate is (Table 5-1)

$$Q_{\text{vent}_6} := 139 \text{ cfm}$$

The initial OH concentration shown in Figure 3-15 is

$$\text{OH}_{\text{hanford_data}_6} := \frac{.275\text{M} + .262\text{M}}{2}$$

$$\text{OH}_{\text{hanford_data}_6} = 0.269 \text{ M}$$

$$\text{CO3}_6 := \frac{20000 \frac{\text{mole}}{\text{yr}} \cdot 20\text{yr}}{V_{\text{sup}_6}}$$

$$\text{ii} := 6$$



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$$Q := Q_{vent_{ii}}$$

$$T_{sup} := T_{sup_aws}$$

$$OH_{data} := OH_{hanford_data_{ii}}$$

$$CO3_{bulk} := CO3_{ii}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .9 \cdot OH_{data}$$

$$CO3_{i_guess} := 1.16 \cdot CO3_{bulk}$$

$$OH_{liq_mass_transfer} := \omega_{OH_{liq}}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_{liq}} := \omega_{CO2_{liq}}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 259 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_{air}}(\Delta T_{hanford_{ii}}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 260.469 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.814 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_{liq}}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.84 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 9.56 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 9.198 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

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OH Depletion Rate

The OH depletion rate is twice the CO₂ rate and given by

$$OH_{dep_hanford_ogden_ii} := \frac{OH_{dep}}{V_{sup_ii}}$$

$$OH_{dep_hanford_ogden_ii} = 0.031 \frac{M}{yr}$$

The maximum OH depletion rate is

$$OH_{dep_max} := \frac{2x_{co2_amb} \cdot C_{air} \cdot Q_{vent_ii}}{V_{sup_ii}}$$

$$OH_{dep_max} = 0.111 \frac{M}{yr}$$

The depletion rate based on the Hobbs model is

$$OH_{dep_hanford_hobbs_ii} := \frac{2x_{co2_amb} \cdot C_{air} \cdot Q_{vent_ii} \cdot F_{hobbs}(OH_{hanford_data_ii})}{V_{sup_ii}}$$

$$OH_{dep_hanford_hobbs_ii} = 0.072 \frac{M}{yr}$$

The caustic depletion data is shown in the figure below. The depletion rate is

$$OH_{dep_hanford_data_ii} := 1.12 \cdot 10^{-5} \frac{M}{day}$$

$$OH_{dep_hanford_data_ii} = 4.091 \times 10^{-3} \frac{M}{yr}$$

The carbon dioxide absorption rate based on the Hanford OH concentration data is

$$F_{hanford_data_ii} := \frac{\frac{OH_{dep_hanford_data_ii}}{2} \cdot V_{sup_ii}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent_ii}}$$

$$F_{hanford_data_ii} = 0.037$$

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$$F_{\text{hanford_ogden}_i} := \frac{\text{OH}_{\text{dep_hanford_ogden}_i} \cdot V_{\text{sup}_i}}{2 \cdot x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i}}$$

$$F_{\text{hanford_ogden}_i} = 0.276$$

$$i_{\text{data}} := 10 + i_i$$

$$\text{OH}_{\text{depcalc}_i} := \text{OH}_{\text{dep}}$$

$$\text{OH}_{\text{depdata}_i} := \text{OH}_{\text{dep_hanford_data}_i} \cdot V_{\text{sup}_i}$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dephobbs}_i} := 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q \cdot F_{\text{hobbs}}(\text{OH}_{\text{data}})$$

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Figure 3-15. AW-105 Caustic Depletion Data.

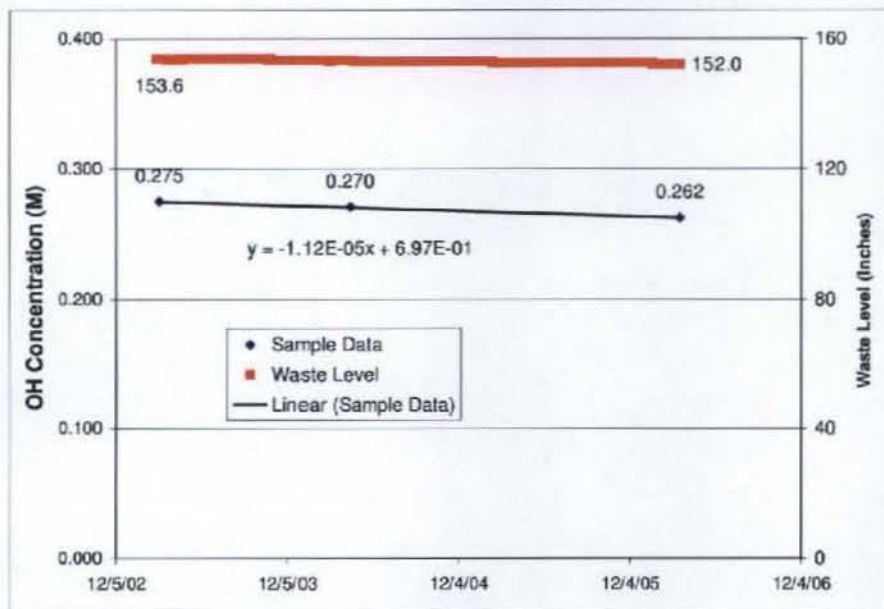
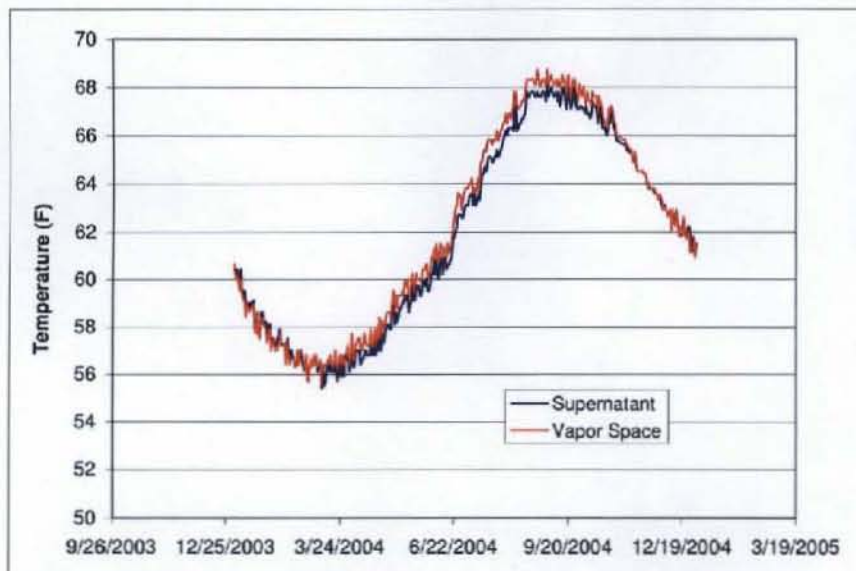


Figure 3-16. AW-105 Waste Temperatures.



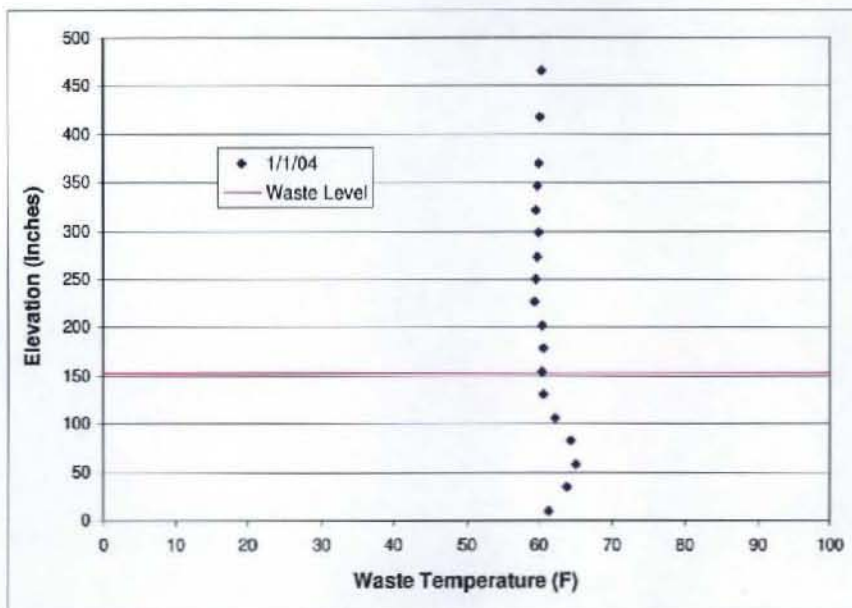


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Figure 3-17. AW-105 Waste Temperature Profile.



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3.1.7 Tank AY-102

The OH and waste volume data is shown in Figure 3-18, RPP-26676. The initial waste volume during the period is used for the evaluation since the data is corrected for the dilution of the nitrite addition

$$V_{\text{waste_ay2}} := 639000 \text{ gal}$$

The sludge volume, HNF-BP-0182, is

$$V_{\text{solids_ay2}} := 151 \text{ kgal}$$

The supernatant volume is

$$V_{\text{sup}_7} := V_{\text{waste_ay2}} - V_{\text{solids_ay2}}$$

$$V_{\text{sup}_7} = 488 \text{ kgal}$$

The annual supernatant and dome temperatures are shown in Figure 3-19, TWINS 2005. The average dome and supernatant temperatures are

$$T_{\text{sup_ay2}} := 100^\circ\text{F}$$

$$\Delta T_{\text{hanford}_7} := 3.1^\circ\text{F}$$

The primary tank ventilation system flow rate (Excel file 702_AZ_flows) in 2000 and 2001 is shown in Figure 3-20. The average over this period is

$$Q_{\text{vent}_7} := 425 \text{ cfm}$$

The initial OH concentration (Figure 3-18) is

$$\text{OH}_{\text{hanford_data}_7} := \frac{1.055\text{M} + .846\text{M}}{2}$$

$$\text{OH}_{\text{hanford_data}_7} = 0.951 \text{ M}$$

$$\text{CO}_3 := \frac{60000 \frac{\text{mole}}{\text{yr}} \cdot 15 \text{ yr}}{V_{\text{sup}_7}}$$

$$ii := 7$$



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$$Q := Q_{vent_i}$$

$$T_{sup} := T_{sup_ay2}$$

$$OH_{data} := OH_{hanford_data_i}$$

$$CO3_{bulk} := CO3_{ii}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .77 \cdot OH_{data}$$

$$CO3_{i_guess} := 2.6 \cdot CO3_{bulk}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 97.5 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{hanford_i}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 97.973 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.477 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.481 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 6.956 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 7.404 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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OH Depletion Rate

The OH depletion rate is twice the CO₂ rate and given by

$$OH_{dep_hanford_ogden_ii} := \frac{OH_{dep}}{V_{sup_ii}}$$

$$OH_{dep_hanford_ogden_ii} = 0.08 \frac{M}{yr}$$

The maximum OH depletion rate is

$$OH_{dep_max} := \frac{2x_{co2_amb} \cdot C_{air} \cdot Q_{vent_ii}}{V_{sup_ii}}$$

$$OH_{dep_max} = 0.11 \frac{M}{yr}$$

The depletion rate based upon the Hobbs model is

$$OH_{dep_hanford_hobbs_ii} := \frac{2x_{co2_amb} \cdot C_{air} \cdot Q_{vent_ii} \cdot F_{hobbs}(OH_{hanford_data_ii})}{V_{sup_ii}}$$

$$OH_{dep_hanford_hobbs_ii} = 0.081 \frac{M}{yr}$$

The caustic depletion data is shown in the figure below. The depletion rate is

$$OH_{dep_hanford_data_ii} := 3.58 \cdot 10^{-4} \frac{M}{day}$$

$$OH_{dep_hanford_data_ii} = 0.131 \frac{M}{yr}$$

$$OH_{dep_hanford_data_ii} := OH_{dep_max}$$

This exceeds the maximum depletion rate for the assumed ventilation flow rate. The maximum depletion rate will be used to compare to the calculation

The carbon dioxide absorption rate based on the Hanford OH concentration data is

$$F_{hanford_data_ii} := \frac{\frac{OH_{dep_hanford_data_ii}}{2} \cdot V_{sup_ii}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent_ii}}$$

$$F_{hanford_data_ii} = 1$$

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$$F_{\text{hanford_ogden}} := \frac{\frac{OH_{\text{dep_hanford_ogden}}}{2} \cdot V_{\text{sup}}}{x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}}}$$

$$F_{\text{hanford_ogden}} = 0.728$$

$$i_{\text{data}} := 10 + ii$$

$$OH_{\text{depcalc}} := OH_{\text{dep}}$$

$$OH_{\text{depdata}} := OH_{\text{dep_hanford_data}} \cdot V_{\text{sup}}$$

The depletion rate based upon the Hobbs model is

$$OH_{\text{dephobbs}} := 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q \cdot F_{\text{hobbs}}(OH_{\text{data}})$$



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Figure 3-18. AY-102 Caustic Depletion Data.

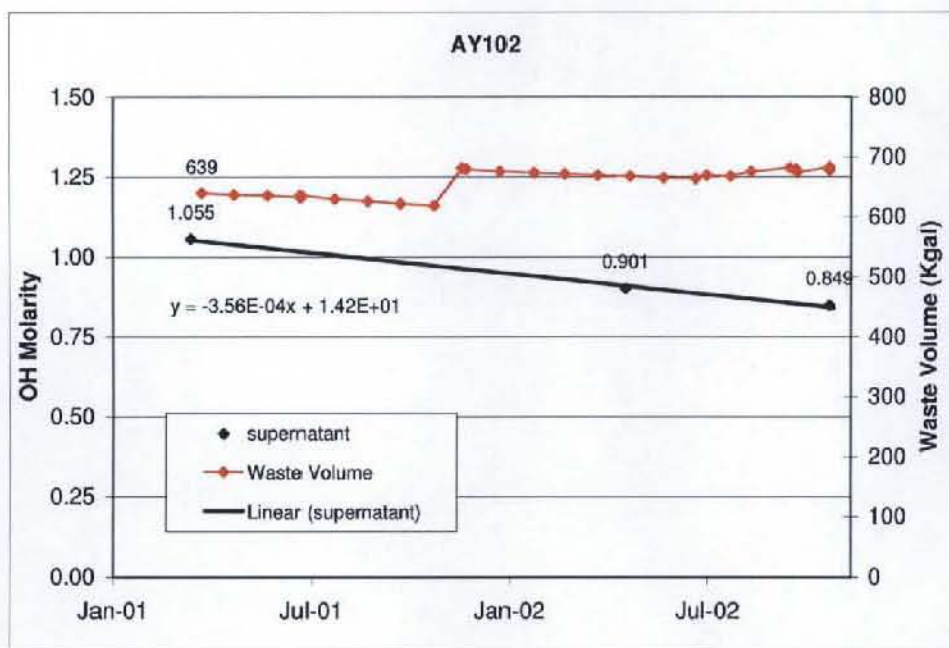
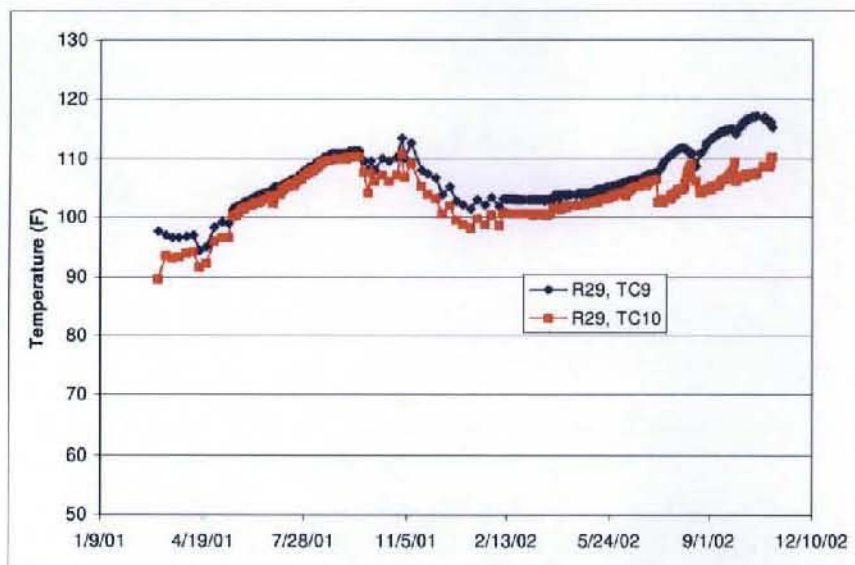


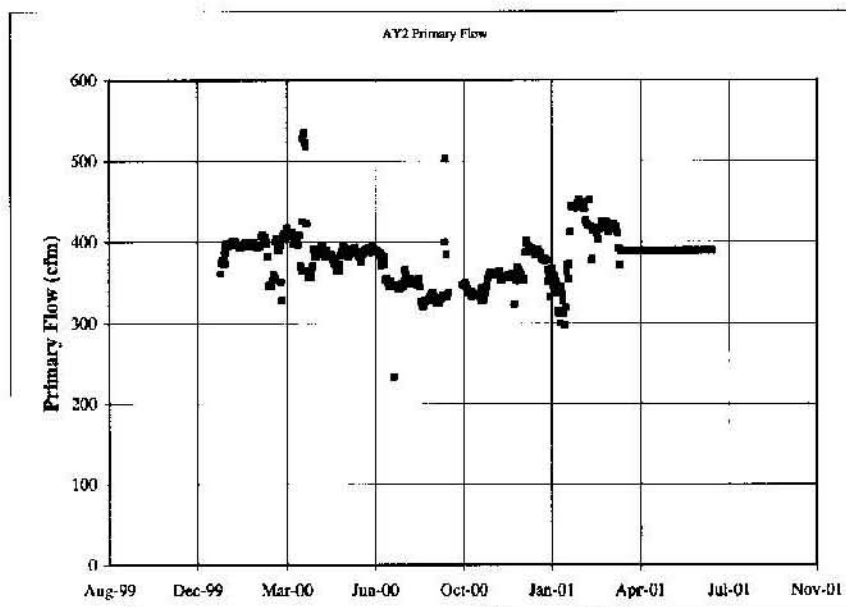
Figure 3-19. AY-102 Temperature Data



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Figure 3-20. AY-102 Primary Ventilation Flow Rate.

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Correction of OH Data

Figure 3-12 show a level increase in November 2001. This was a result of a nitrite addition to the tank. This caused a dilution in the supernatant hydroxide concentration. The second and third data points in Figure 3-12 were corrected for this dilution to give the hydroxide concentrations is the dilution did not occur. In addition to the nitrite addition the level increases slowly because of condensate returned to this tank later in the evaluation period. However, this water layered on top of the supernatant and did not significantly effect the bulk supernatant OH concentration. This dilution affects of the nitrite addition only will be used for the fourth point.

The supernatant volume for the first data point is

$$\text{Vol_sup}_1 := 639\text{kgal} - V_{\text{solids_ay2}}$$

The supernatant volume for the 2nd points is

$$\text{Vol_sup}_2 := 667\text{kgal} - V_{\text{solids_ay2}}$$

The supernatant volume for the third point is

$$\text{Vol_sup}_3 := 677\text{kgal} - V_{\text{solids_ay2}}$$

The correction for point 2 is calculated.

The measured hydroxide concentration is

$$\text{OH}_2 := .85\text{M}$$

The number of mole of hydroxide is

$$\text{mole}_{\text{OH}} = \text{OH}_2 \cdot \text{Vol_sup}_2$$

The hydroxide concentration without the nitrite addition is then

$$\text{OH}_{2_init} = \frac{\text{mole}_{\text{OH}}}{\text{Vol_sup}_1}$$

$$\text{OH}_{2_init} := \text{OH}_2 \cdot \frac{\text{Vol_sup}_2}{\text{Vol_sup}_1}$$

$$\text{OH}_{2_init} = 0.899\text{M}$$

Similiarly, measured concentration at point three is

$$\text{OH}_3 := 0.785\text{M}$$

$$\text{OH}_{3_init} := \text{OH}_3 \cdot \frac{\text{Vol_sup}_3}{\text{Vol_sup}_1}$$

$$\text{OH}_{3_init} = 0.846\text{M}$$

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3.1.7 Tank AY-102

The OH and waste volume data is shown in Figure 3-21. The initial waste volume during the period is used for the evaluation since the data is corrected for the dilution of the nitrite addition

$$V_{\text{waste_ay2}} := 166 \text{ in} \cdot A_{\text{tank}}$$

$$V_{\text{waste_ay2}} = 457.163 \text{ kgal}$$

$$V_{\text{solids}} := 8 \text{ in} \cdot A_{\text{tank}}$$

$$V_{\text{solids}} = 22.032 \text{ kgal}$$

The supernatant volume is

$$V_{\text{sup}_8} := V_{\text{waste_ay2}} - V_{\text{solids}}$$

$$V_{\text{sup}_8} = 435.131 \text{ kgal}$$

$$\Delta T_{\text{hanford}_8} := 4 \text{ F}$$

The primary tank ventilation system flow rate (Excel file 702_AZ_flows) in 2000 and 2001 is shown in Figure 3-23. The average over this period is

$$Q_{\text{vent}_8} := Q_{\text{vent}_7}$$

The initial OH concentration (Figure 3-21) is

$$\text{OH}_{\text{hanford_data}_8} := \frac{.586 \text{ M} + .441 \text{ M}}{2}$$

$$\text{OH}_{\text{hanford_data}_8} = 0.513 \text{ M}$$

$$\text{CO}_{3_8} := \frac{50000 \frac{\text{mole}}{\text{yr}} \cdot 15 \text{ yr}}{V_{\text{sup}_8}}$$

$$ii := 8$$

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$$Q := Q_{vent_{ii}}$$

$$T_{sup} := T_{sup_ay2}$$

$$OH_{data} := OH_{hanford_data_{ii}}$$

$$CO3_{bulk} := CO3_{ii}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .59 \cdot OH_{data}$$

$$CO3_{i_guess} := 2.8 \cdot CO3_{bulk}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 91.7 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{hanford_{ii}}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 91.713 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.422 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.516 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 7.314 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 7.581 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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OH Depletion Rate

The OH depletion rate is twice the CO_2 rate and given by

$$\text{OH}_{\text{dep_hanford_ogden}_u} := \frac{\text{OH}_{\text{dep}}}{V_{\text{sup}_u}}$$

$$\text{OH}_{\text{dep_hanford_ogden}_u} = 0.092 \frac{\text{M}}{\text{yr}}$$

The maximum OH depletion rate is

$$\text{OH}_{\text{dep_max}} := \frac{2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_u}}{V_{\text{sup}_u}}$$

$$\text{OH}_{\text{dep_max}} = 0.124 \frac{\text{M}}{\text{yr}}$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dep_hanford_hobbs}_u} := \frac{2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_u} \cdot R_{\text{hobbs}}(\text{OH}_{\text{hanford_data}_u})}{V_{\text{sup}_u}}$$

$$\text{OH}_{\text{dep_hanford_hobbs}_u} = 0.086 \frac{\text{M}}{\text{yr}}$$

The caustic depletion data is shown in the figure below. The depletion rate is

$$\text{OH}_{\text{dep_hanford_data}_u} := 1.05 \cdot 10^{-3} \frac{\text{M}}{\text{day}}$$

$$\text{OH}_{\text{dep_hanford_data}_u} = 0.384 \frac{\text{M}}{\text{yr}}$$

$$\text{OH}_{\text{dep_hanford_data}_u} := \text{OH}_{\text{dep_max}}$$

This exceeds the maximum depletion rate for the assumed ventilation flow rate. The maximum depletion rate will be used to compare to the calculation

The carbon dioxide absorption rate based on the Hanford OH concentration data is

$$F_{\text{hanford_data}_u} := \frac{\frac{\text{OH}_{\text{dep_hanford_data}_u}}{2} \cdot V_{\text{sup}_u}}{x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_u}}$$

$$F_{\text{hanford_data}_u} = 1$$

$$F_{\text{hanford_ogden}_u} := \frac{\frac{\text{OH}_{\text{dep_hanford_ogden}_u}}{2} \cdot V_{\text{sup}_u}}{x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_u}}$$

$$F_{\text{hanford_ogden}_u} = 0.745$$



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$$i_{data} := 10 + ii$$

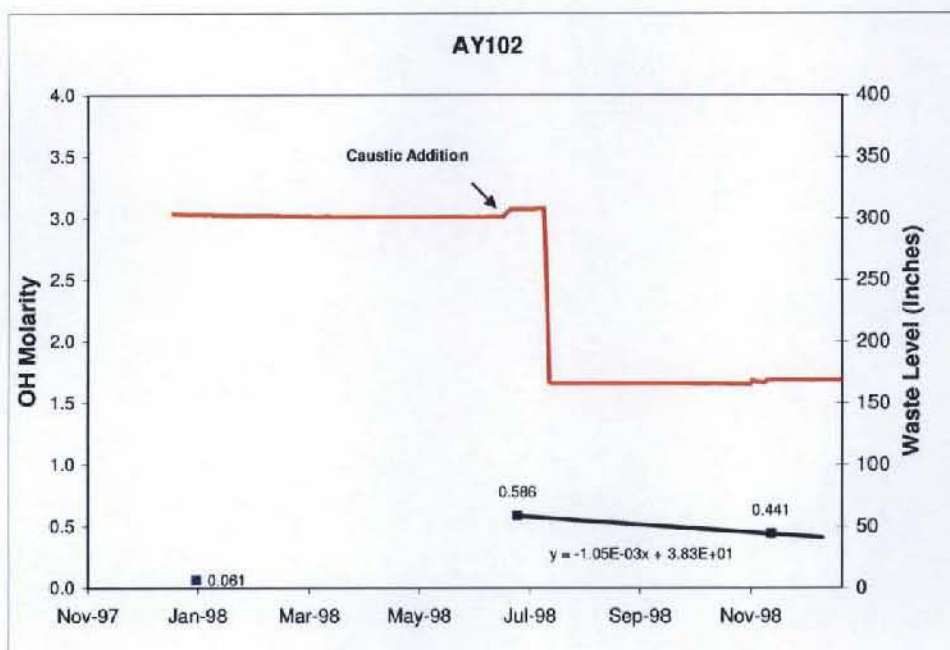
$$OH_{depalc, i_{data}} := OH_{dep}$$

$$OH_{depdata, i_{data}} := OH_{dep_hanford_data, ii} \cdot V_{sup, ii}$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs, i_{data}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

Figure 3-21. AY-102 Caustic Depletion Data.





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Figure 3-22. AY-102 Waste Temperature Profile.

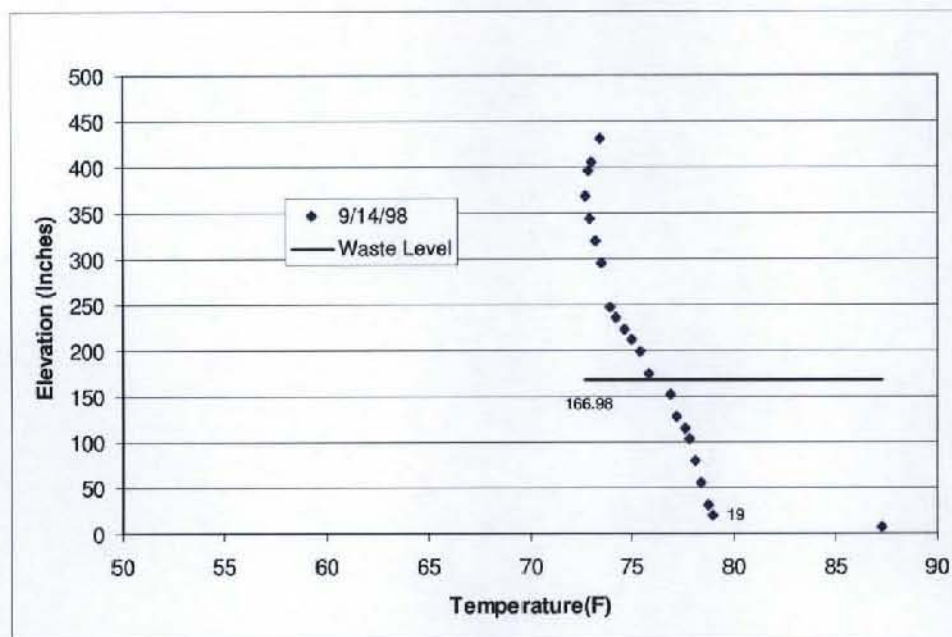
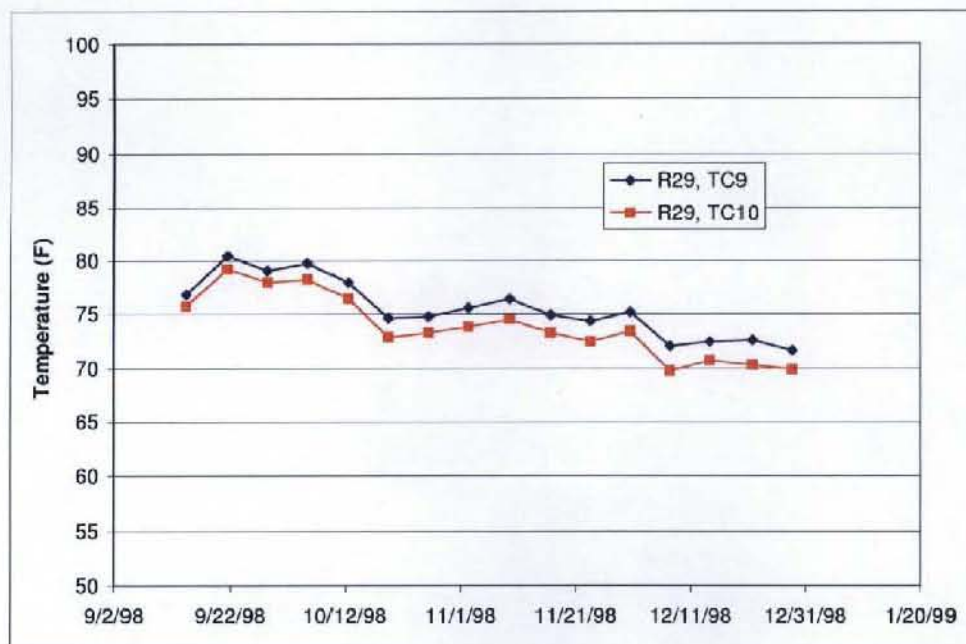


Figure 3-23. AY-102 Vapor Space and Supernatant Temperatures.



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3.1.8 Tank AZ-101

ii := 9

The OH and waste volume data is shown in Figure 3-24, RPP-26676. The average waste volume during the period of evaluation is

$$V_{\text{waste_az1}} := 916000 \text{ gal}$$

The sludge volume, HNF-EP-0182, is

$$V_{\text{solids_az1}} := 52000 \text{ gal}$$

The supernatant volume is

$$V_{\text{sup_ii}} := V_{\text{waste_az1}} - V_{\text{solids_az1}}$$

$$V_{\text{sup_ii}} = 864 \text{ kgal}$$

The annual supernatant temperatures are shown in Figure 3-25, TWINS 2005. The average supernatant temperatures are

$$T_{\text{sup_az1}} := 140 \text{ F}$$

There is not a vapor space temperature. The average temperature difference for all Hanford tanks will be used (Section 3.3)

$$\Delta T_{\text{hanford_ii}} := 2.0 \text{ F}$$

The primary tank ventilation system flow rate is (Excel file 702AZ_flows)

$$Q_{\text{vent_ii}} := 149 \text{ cfm}$$

The initial OH concentration (Figure 3-24) is

$$\text{OH}_{\text{hanford_data_ii}} := \frac{0.9 \text{ M} + .727 \text{ M}}{2}$$

$$\text{OH}_{\text{hanford_data_ii}} = 0.813 \text{ M}$$

$$\text{CO3}_{\text{az1}} := \frac{5000 \frac{\text{mole}}{\text{yr}} \cdot 10 \text{ yr}}{V_{\text{sup_ii}}}$$

$$\text{CO3}_{\text{az1}} = 0.015 \text{ M}$$



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$$Q := Q_{vent_i}$$

$$T_{sup} := T_{sup_az1}$$

$$CO3_{bulk} := CO3_{az1}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .82 \cdot OH_{data}$$

$$CO3_{i_guess} := 24 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.367 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 48.5 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{hanford_i}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 48.525 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 6.245 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 6.171 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 3.138 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 3.086 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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OH Depletion Rate

The OH depletion rate is twice the CO₂ rate and given by

$$OH_{dep_hanford_ogden} := \frac{OH_{dep}}{V_{sup_ii}}$$

$$OH_{dep_hanford_ogden} = 0.019 \frac{M}{yr}$$

The maximum OH depletion rate is

$$OH_{dep_max} := \frac{2x_{co2_amb} \cdot C_{air} \cdot Q_{vent_ii}}{V_{sup_ii}}$$

$$OH_{dep_max} = 0.022 \frac{M}{yr}$$

The depletion rate based upon the Hobbs model is

$$OH_{dep_hanford_hobbs} := \frac{2x_{co2_amb} \cdot C_{air} \cdot Q_{vent_ii} \cdot F_{hobbs}(OH_{hanford_data_ii})}{V_{sup_ii}}$$

$$OH_{dep_hanford_hobbs} = 0.016 \frac{M}{yr}$$

The caustic depletion data is shown in the figure below. The depletion rate is

$$OH_{dep_hanford_data} := 4.01 \cdot 10^{-5} \frac{M}{day}$$

$$OH_{dep_hanford_data} = 0.015 \frac{M}{yr}$$

The carbon dioxide absorption rate based on the Hanford OH concentration data is

$$F_{hanford_data} := \frac{\frac{OH_{dep_hanford_data}}{2} \cdot V_{sup_ii}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent_ii}}$$

$$F_{hanford_data} = 0.672$$

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$$F_{\text{hanford_ogden}_i} := \frac{\frac{\text{OH}_{\text{dep_hanford_ogden}_i}}{2} \cdot V_{\text{sup}_i}}{x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i}}$$

$$F_{\text{hanford_ogden}_i} = 0.865$$

$$i_{\text{data}} := 10 + ii$$

$$\text{OH}_{\text{depcalc}_{i_{\text{data}}}} := \text{OH}_{\text{dep}}$$

$$\text{OH}_{\text{depdata}_{i_{\text{data}}}} := \text{OH}_{\text{dep_hanford_data}_i} \cdot V_{\text{sup}_i}$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dephobbs}_{i_{\text{data}}}} := 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q \cdot F_{\text{hobbs}}(\text{OH}_{\text{data}})$$



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Figure 3-24. AZ-101 Caustic Depletion Data.

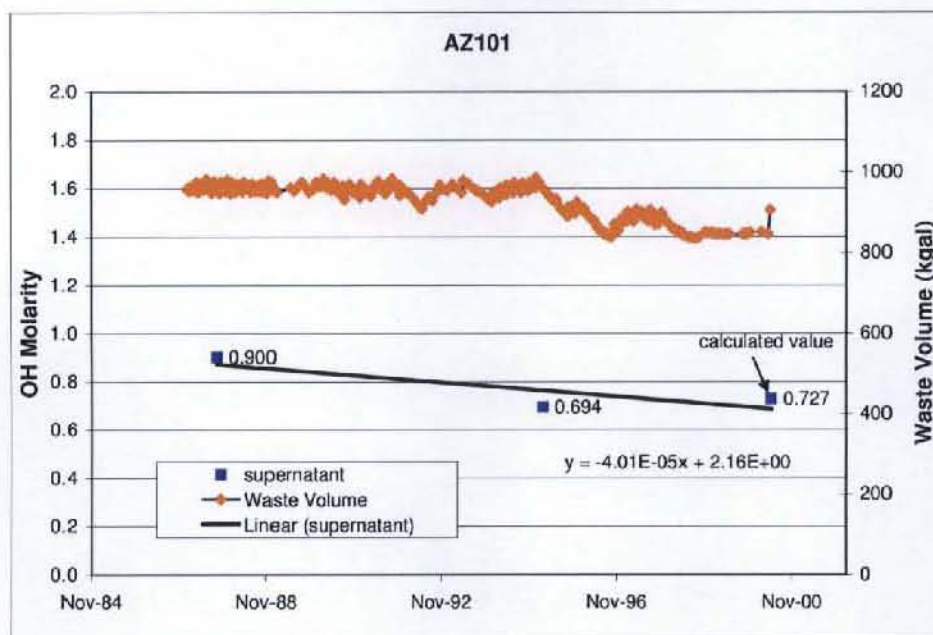


Figure 3-25. AZ-101 Waste Temperatures.



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3.1.9 Tank AZ-102 (2/95 to 10/01)

The OH and waste volume data is shown in Figure 3-26, RPP-26676. The evaluation is broken up into two periods. The first is from 2/95 to 7/99. The average waste volume during the period of evaluation is

$$V_{\text{waste_az2}} := \frac{(927 + 997)}{2} \text{ kgal}$$

$$V_{\text{waste_az2}} = 962 \text{ kgal}$$

The sludge volume is (Hanlon 2003)

$$V_{\text{solids_az2}} := 105000 \text{ gal}$$

The supernatant volume is

$$V_{\text{sup_10}} := V_{\text{waste_az2}} - V_{\text{solids_az2}}$$

$$V_{\text{sup_10}} = 857 \text{ kgal}$$

The annual supernatant temperatures are shown in Figure 3-27, TWINS 2005. The average supernatant temperature is

$$T_{\text{sup_az2}} := 110.9\text{F}$$

The vapor temperature is not available. The average temperature difference for all Hanford tanks will be used (Section 3.3)

$$\Delta T_{\text{hanford_10}} := 2.0\text{F}$$

The average dome temperature used for the evaluation is

$$T_{\text{dome_az2}} := T_{\text{sup_az2}} - \Delta T_{\text{hanford_10}}$$

The primary tank ventilation system flow rate is (Excel file 702AZ_flows)

$$Q_{\text{vent_10}} := 102 \text{ cfm}$$

The initial OH concentration (Figure 3-26) is

$$\text{OH}_{\text{hanford_data_10}} := \frac{.011\text{M} + .02\text{M}}{2}$$

$$\text{OH}_{\text{hanford_data_10}} = 0.016\text{M}$$

$$\text{CO3}_{\text{az1}} := \frac{5000 \frac{\text{mole}}{\text{yr}} \cdot 10\text{yr}}{V_{\text{sup_10}}}$$

$$\text{CO3}_{\text{az1}} = 0.015\text{M}$$

$$ii := 10$$

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$$Q := Q_{vent_{ii}}$$

$$T_{sup} := T_{sup_{az1}}$$

$$CO3_{bulk} := CO3_{az1}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .874 \cdot OH_{data}$$

$$CO3_{i_guess} := 17 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.262 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 34.7 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{hanford_ii}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 34.465 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 4.371 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 4.415 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 2.201 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 2.208 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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OH Depletion Rate

The OH depletion rate is twice the CO₂ rate and given by

$$OH_{dep_hanford_ogden_ii} := \frac{OH_{dep}}{V_{sup_ii}}$$

$$OH_{dep_hanford_ogden_ii} = 0.014 \frac{M}{yr}$$

The maximum OH depletion rate is

$$OH_{dep_max} := \frac{2x_{co2_amb} \cdot C_{air} \cdot Q_{vent_ii}}{V_{sup_ii}}$$

$$OH_{dep_max} = 0.015 \frac{M}{yr}$$

The depletion rate based on the Hobbs model is

$$OH_{dep_hanford_hobbs_ii} := \frac{2x_{co2_amb} \cdot C_{air} \cdot Q_{vent_ii} \cdot F_{hobbs}(OH_{hanford_data_ii})}{V_{sup_ii}}$$

$$OH_{dep_hanford_hobbs_ii} = 6.659 \times 10^{-3} \frac{M}{yr}$$

The caustic depletion data is shown in the figure below. The depletion rate is

$$OH_{dep_hanford_data_ii} := 1.14 \cdot 10^{-5} \frac{M}{day}$$

$$OH_{dep_hanford_data_ii} = 4.164 \times 10^{-3} \frac{M}{yr}$$

The carbon dioxide absorption rate based on the Hanford OH concentration data is

$$F_{hanford_data_ii} := \frac{\frac{OH_{dep_hanford_data_ii}}{2} \cdot V_{sup_ii}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent_ii}}$$

$$F_{hanford_data_ii} = 0.277$$

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$$F_{\text{hanford_ogden}_i} := \frac{\frac{\text{OH}_{\text{dep_hanford_ogden}_i}}{2} \cdot V_{\text{sup}_i}}{x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i}}$$

$$F_{\text{hanford_ogden}_i} = 0.904$$

$$i_{\text{data}} := 10 + ii$$

$$\text{OH}_{\text{depcalc}_i} := \text{OH}_{\text{dep}}$$

$$\text{OH}_{\text{depdata}_i} := \text{OH}_{\text{dep_hanford_data}_i} \cdot V_{\text{sup}_i}$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dephobbs}_i} := 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q \cdot F_{\text{hobbs}}(\text{OH}_{\text{data}})$$



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Figure 3-26. AZ-102 Caustic Depletion Data.

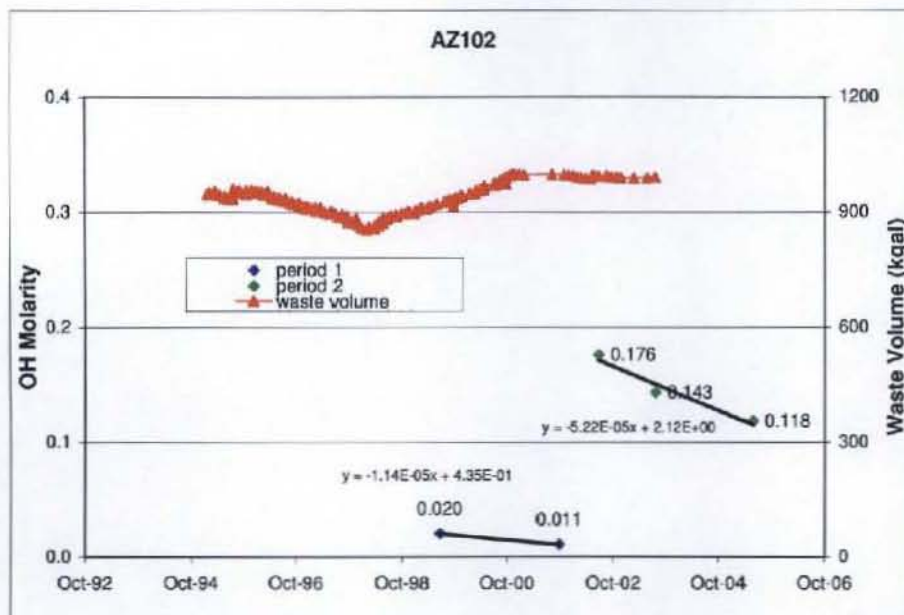
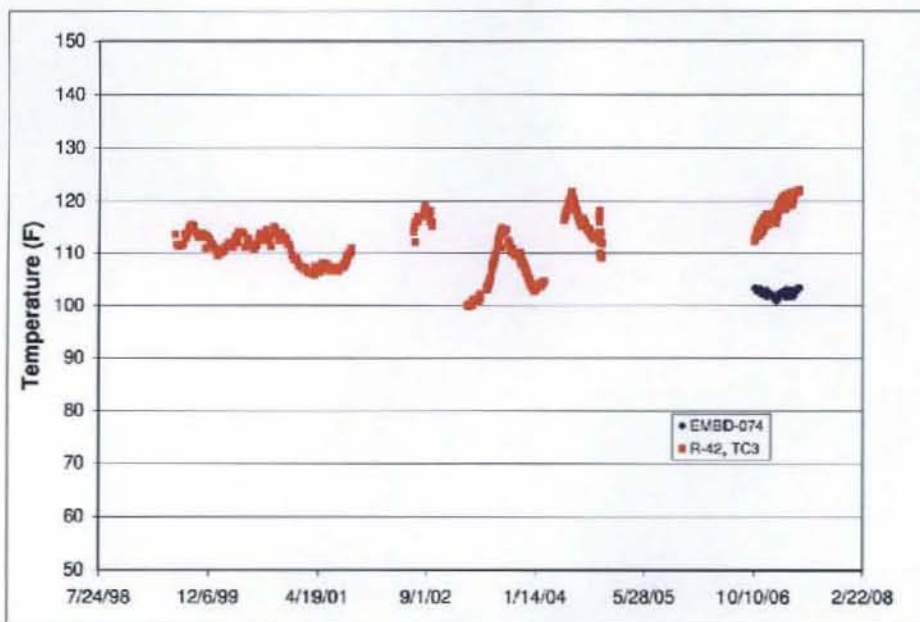


Figure 3-27. AZ-102 Waste Temperatures.



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3.1.10 Tank AZ-102 (7/2002 to June 2005)

The OH and waste volume data is shown in Figure 3-14, RPP-26676. The average waste volume during the period of evaluation is

$$V_{\text{waste_az2}} := 996000 \text{ gal}$$

The sludge volume is (Hanlon 2003)

$$V_{\text{solids_az2}} := 105000 \text{ gal}$$

The supernatant volume is

$$V_{\text{sup_11}} := V_{\text{waste_az2}} - V_{\text{solids_az2}}$$

$$V_{\text{sup_11}} = 891 \text{ kgal}$$

The annual supernatant temperatures are shown in Figure 3-15, TWINS 2005. The average supernatant temperature is

$$T_{\text{sup_az2}} := 110.9 \text{ F}$$

The average temperature difference for all Hanford tanks will be used (Section 3.3)

$$\Delta T_{\text{hanford_11}} := 2.0 \text{ F}$$

The average dome temperature used for the evaluation is

$$T_{\text{dome_az2}} := T_{\text{sup_az2}} - \Delta T_{\text{hanford_10}}$$

The primary tank ventilation system flow rate is (Excel file 702AZ_flows)

$$Q_{\text{vent_11}} := 102 \text{ cfm}$$

The initial OH concentration (Figure 3-14) is

$$\text{OH}_{\text{hanford_data_11}} := \frac{.176 \text{ M} + .118 \text{ M}}{2}$$

$$\text{OH}_{\text{hanford_data_11}} = 0.147 \text{ M}$$

$$\text{CO3}_{\text{az1}} := \frac{5000 \frac{\text{mole}}{\text{yr}} \cdot 10 \text{ yr}}{V_{\text{sup_11}}}$$

$$\text{CO3}_{\text{az1}} = 0.015 \text{ M}$$

ii := 11

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$$Q := Q_{vent_{ii}}$$

$$T_{sup} := T_{sup_{az1}}$$

$$CO3_{bulk} := CO3_{az1}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .87 \cdot OH_{data}$$

$$CO3_{i_guess} := 18 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.267 M$$

$$OH_{liq_mass_transfer} := \omega_{OH_{liq}}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_{liq}} := \omega_{CO2_{liq}}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 34.7 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_{air}}(\Delta T_{hanford_{ii}}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 34.465 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 4.51 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_{liq}}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 4.415 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 2.249 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 2.208 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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OH Depletion Rate

The OH depletion rate is twice the CO_2 rate and given by

$$\text{OH}_{\text{dep_hanford_ogden}} := \frac{\text{OH}_{\text{dep}}}{V_{\text{sup}_i}}$$

$$\text{OH}_{\text{dep_hanford_ogden}} = 0.013 \frac{\text{M}}{\text{yr}}$$

The maximum OH depletion rate is

$$\text{OH}_{\text{dep_max}} := \frac{2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i}}{V_{\text{sup}_i}}$$

$$\text{OH}_{\text{dep_max}} = 0.014 \frac{\text{M}}{\text{yr}}$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dep_hanford_hobbs}} := \frac{2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i} \cdot F_{\text{hobbs}}(\text{OH}_{\text{hanford_data}_i})}{V_{\text{sup}_i}}$$

$$\text{OH}_{\text{dep_hanford_hobbs}} = 8.738 \times 10^{-3} \frac{\text{M}}{\text{yr}}$$

The caustic depletion data is shown in the figure below. The depletion rate is

$$\text{OH}_{\text{dep_hanford_data}} := 5.22 \cdot 10^{-5} \frac{\text{M}}{\text{day}}$$

$$\text{OH}_{\text{dep_hanford_data}} = 0.019 \frac{\text{M}}{\text{yr}}$$

This exceeds the maximum for the assumed ventilation flow rate. The calculation will be compared to the maximum rate.

$$\text{OH}_{\text{dep_hanford_data}} := \text{OH}_{\text{dep_max}}$$

The carbon dioxide absorption rate based on the Hanford OH concentration data is

$$F_{\text{hanford_data}_i} := \frac{\frac{\text{OH}_{\text{dep_hanford_data}_i}}{2} \cdot V_{\text{sup}_i}}{x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i}}$$

$$F_{\text{hanford_data}_i} = 1$$

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$$F_{\text{hanford_ogden}_i} := \frac{\text{OH}_{\text{dep_hanford_ogden}_i} \cdot V_{\text{sup}_i}}{2 \cdot x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i}}$$

$$F_{\text{hanford_ogden}_i} = 0.904$$

$$i_{\text{data}} := 10 + ii$$

$$\text{OH}_{\text{dep_calc}_i} := \text{OH}_{\text{dep}}$$

$$\text{OH}_{\text{dep_data}_i} := \text{OH}_{\text{dep_hanford_data}_i} \cdot V_{\text{sup}_i}$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dep_hobbs}_i} := 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q \cdot F_{\text{hobbs}}(\text{OH}_{\text{data}})$$

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3.1.11 Tank AY-101

The OH and waste volume data is shown in Figure 3-28, RPP-26676. The average waste volume during the period of evaluation is

$$V_{\text{waste_ay1}} := 66.12 \text{ in} \cdot A_{\text{tank}}$$

$$V_{\text{waste_ay1}} = 182.094 \text{ kgal}$$

The sludge volume is (Hanlon 2006)

$$V_{\text{solids_ay1}} := 96 \text{ kgal}$$

The supernatant volume is

$$V_{\text{sup}_{12}} := V_{\text{waste_ay1}} - V_{\text{solids_ay1}}$$

$$V_{\text{sup}_{12}} = 86.094 \text{ kgal}$$

The annual supernatant and dome temperatures are shown in Figure 3-29, TWINS 2005. The average supernatant temperature is

$$T_{\text{dome_ay1}} := 80\text{F}$$

From GOTH analyses

$$\Delta T_{\text{hanford}_{12}} := 9\text{F}$$

The average dome temperature used for the evaluation is

$$T_{\text{sup_ay1}} := T_{\text{dome_ay1}} + \Delta T_{\text{hanford}_{11}}$$

The primary tank ventilation system flow rate is

$$Q_{\text{vent}_{12}} := 340 \text{ cfm}$$

The initial OH concentration (Figure 3-28) is

$$\text{OH}_{\text{hanford_data}_{12}} := \frac{3.09\text{M} + .782\text{M}}{2}$$

$$\text{OH}_{\text{hanford_data}_{12}} = 1.936 \text{ M}$$

$$\text{CO}_{3_{12}} := \frac{60000 \frac{\text{mole}}{\text{yr}} \cdot 15 \text{ yr}}{V_{\text{sup}_{12}}}$$

$$\text{CO}_{3_{12}} = 2.762 \text{ M}$$

$$\text{ii} := 12$$

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$$Q := Q_{vent_{12}}$$

$$T_{sup} := T_{sup_{ay1}}$$

$$OH_{data} := OH_{hanford_{data_{ii}}}$$

$$CO3_{bulk} := CO3_{12}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .9 \cdot OH_{data}$$

$$CO3_{i_guess} := 1.25 \cdot CO3_{bulk}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 60ppm$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{hanford_{ii}}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 60.368 ppm$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.308 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.355 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 6.161 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 6.773 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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OH Depletion Rate

The OH depletion rate is twice the CO_2 rate and given by

$$\text{OH}_{\text{dep_hanford_ogden}_i} := \frac{\text{OH}_{\text{dep}}}{V_{\text{sup}_i}}$$

$$\text{OH}_{\text{dep_hanford_ogden}_i} = 0.416 \frac{\text{M}}{\text{yr}}$$

The maximum OH depletion rate is

$$\text{OH}_{\text{dep_max}} := \frac{2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i}}{V_{\text{sup}_i}}$$

$$\text{OH}_{\text{dep_max}} = 0.499 \frac{\text{M}}{\text{yr}}$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dep_hanford_hobbs}_i} := \frac{2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i} \cdot F_{\text{hobbs}}(\text{OH}_{\text{hanford_data}_i})}{V_{\text{sup}_i}}$$

$$\text{OH}_{\text{dep_hanford_hobbs}_i} = 0.394 \frac{\text{M}}{\text{yr}}$$

The caustic depletion data is shown in the figure below. The depletion rate is

$$\text{OH}_{\text{dep_hanford_data}_i} := 1.12 \cdot 10^{-3} \frac{\text{M}}{\text{day}}$$

$$\text{OH}_{\text{dep_hanford_data}_i} = 0.409 \frac{\text{M}}{\text{yr}}$$

The carbon dioxide absorption rate based on the Hanford OH concentration data is

$$F_{\text{hanford_data}_i} := \frac{\frac{\text{OH}_{\text{dep_hanford_data}_i}}{2} \cdot V_{\text{sup}_i}}{x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i}}$$

$$F_{\text{hanford_data}_i} = 0.819$$

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$$F_{\text{hanford_ogden}_i} := \frac{\frac{\text{OH}_{\text{dep_hanford_ogden}_i}}{2} \cdot V_{\text{sup}_i}}{x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i}}$$

$$F_{\text{hanford_ogden}_i} = 0.832$$

$$\text{OH}_{\text{dep_cond_return}} := 84000 \frac{\text{mole}}{\text{yr}}$$

$$\text{OH}_{\text{dep_cond_return_ogden}_i} := \frac{\text{OH}_{\text{dep_cond_return}}}{V_{\text{sup}_i}}$$

$$\text{OH}_{\text{dep_cond_return_ogden}_i} = 0.258 \frac{\text{M}}{\text{yr}}$$

$$F_{\text{cond_return}_i} := \frac{\frac{\text{OH}_{\text{dep_cond_return_ogden}_i}}{2} \cdot V_{\text{sup}_i}}{x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_i}}$$

$$F_{\text{cond_return}_i} = 0.516$$

$$i_{\text{data}} := 10 + i_i$$

$$\text{OH}_{\text{dep_calc}_i} := \text{OH}_{\text{dep}_i}$$

$$\text{OH}_{\text{dep_data}_i} := \text{OH}_{\text{dep_hanford_data}_i} \cdot V_{\text{sup}_i}$$

$$\text{OH}_{\text{dep_data}_i} = 1.333 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dep_hobbs}_i} := 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q \cdot F_{\text{hobbs}}(\text{OH}_{\text{data}_i})$$

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Figure 3-28. AY-101 Caustic Depletion Data.

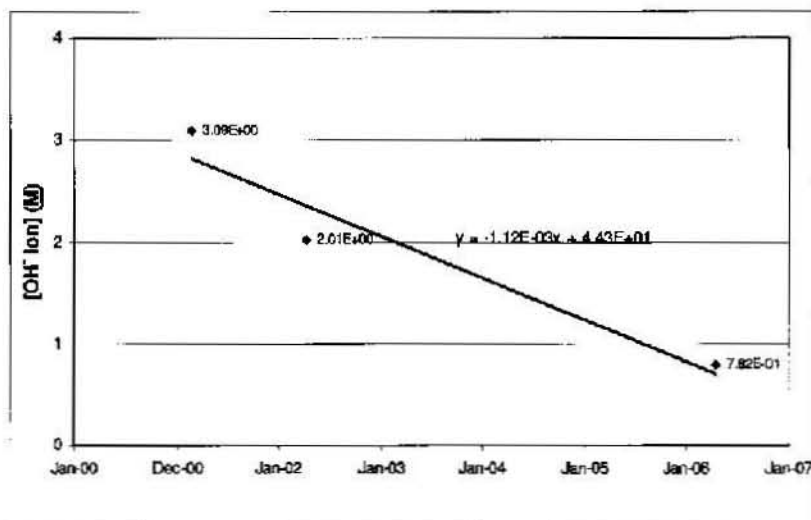
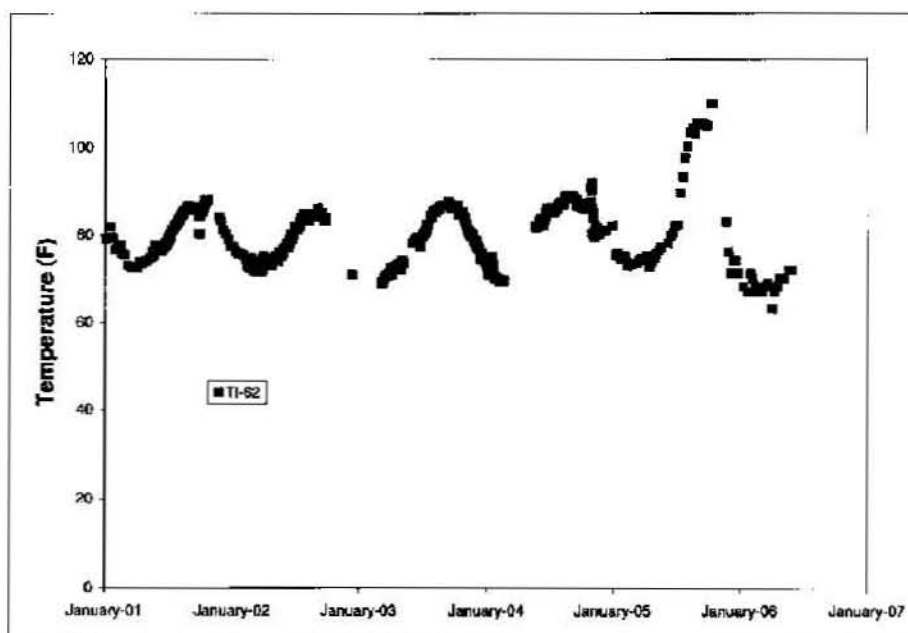


Figure 3-29 Tank 241-AY-101 Vapor Space Temperature

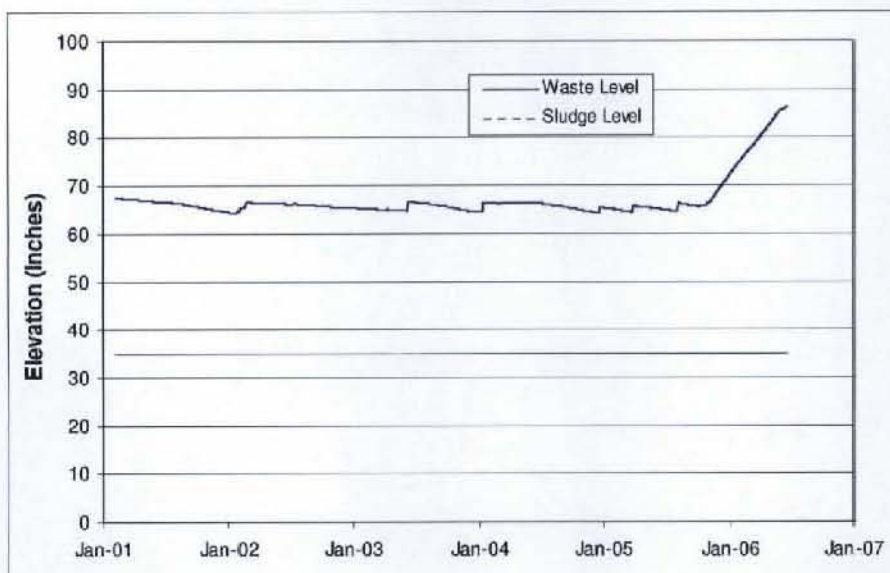
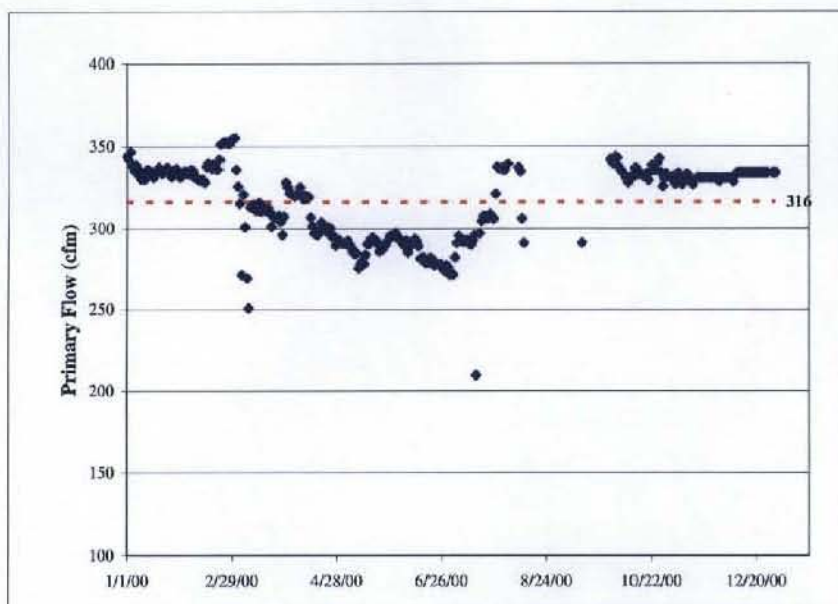




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Figure 3-30 Tank 241-AY-101 Waste Level.**Figure 3-31 Tank 241-AY-101 Primary Ventilation Flow.**

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3.2 AVERAGE DOME AND SUPERNATANT TEMPERATURE DIFFERENCE

The temperature difference between the dome and supernatant is not know for the SRL tanks. The average of the three Hanford Tanks (not to include the Aging Waste Tanks) is used in Section 3.2.

$$\Delta T_{\text{hanford_ave}} := \frac{\sum_{i=1}^{12} \Delta T_{\text{hanford}_i}}{12}$$

$$\Delta T_{\text{hanford_ave}} = 2.228 \text{ F}$$

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4.0 LABORATORY HYDROXIDE DEPLETION TESTS

4.1 INTRODUCTION

A series of test were performed in the laboratory to evaluate the effects of CO_2 absorption on low hydroxide samples contained in beakers, FH-0302630, *Report on the Evaluation of Potentiometric Titrations to Determine Hydroxide*. These data are used to benchmark the hydroxide depletion model presented in Section 2.0.

The tests to measure the CO_2 absorption rate from vials used 15 to 20 mL scintillation vials which contained 10 mL of .01 M hydroxide solution, Figure 5-1. The samples were slowly stirred for varying times and the hydroxide titrated to determine the concentration at 20 minute intervals, FH-0302360. It is assumed that the samples were in thermal equilibrium with the ambient air.

Figure 5-1 Kelly Carothers November 14, 2005 E:mail.

Donald Ogden

From: "Ogden, Donald M" <Donald_M_Ogden@RL.gov>
To: <dmogden@icehouse.net>
Sent: Monday, November 14, 2005 8:07 AM
Subject: FW: Core 317, Segment 18 DL evaluation

-----Original Message-----

From: Carothers, Kelly G
Sent: Wednesday, November 09, 2005 7:45 AM
To: Ogden, Donald M
Subject: RE: Core 317, Segment 18 DL evaluation

Don,

The reference with the data is letter FH-0302630, "Report on the Evaluation of Potentiometric Titrations to Determine Hydroxide." The section on the carbon dioxide absorption effect on hydroxide starts on page 25. If you have access to RMIS, you can view the report through that database; otherwise I can fax you the 3 pages of the report with the discussion.

The beakers used in the tests were 15-20 mL scintillation vials with 10 mL of 0.01 M hydroxide solution. The internal diameter of these vials is 1 inch. The neck is narrower, but the solution would be at the 1 inch diameter region.



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The hydroxide depletion rate based upon the CO₂ absorption tests are shown in Figure 5-2. Measurements were obtained every 20 minutes. The OH⁻ ion depletion rate is calculated for each 20 minute period as shown in Figure 5-2.

$$\text{OH}_{\text{dep_lab}_1} := 6.3 \cdot 10^{-5} \frac{\text{M}}{\text{min}}$$

$$\text{OH}_{\text{dep_lab}_2} := 6.78 \cdot 10^{-5} \frac{\text{M}}{\text{min}}$$

$$\text{OH}_{\text{dep_lab}_3} := 7 \cdot 10^{-5} \frac{\text{M}}{\text{min}}$$

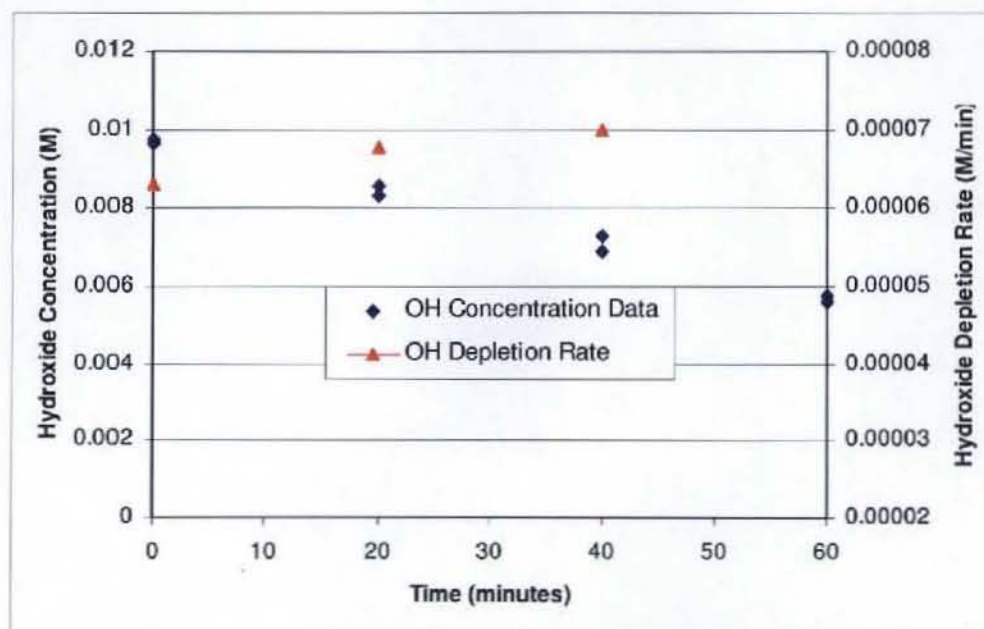
$$\text{OH}_{\text{vial}_0} := .009695\text{M}$$

$$\text{OH}_{\text{vial}_1} := .008435\text{M}$$

$$\text{OH}_{\text{vial}_2} := .00708\text{M}$$

$$\text{OH}_{\text{vial}_3} := .00568\text{M}$$

Figure 4-1 CO₂ Absorption Test Data.



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4.2 CO₂ ABSORPTION TEST INPUT PARAMETERS

Input parameters for the CO₂ absorption test are given in Figure 5-1 and FH-0302630. The inside diameter of the vial is

$$D_{\text{vial}} := 1 \text{ in}$$

The surface area is

$$A_{\text{vial}} := \frac{\pi D_{\text{vial}}^2}{4}$$

$$A_{\text{vial}} = 0.785 \text{ in}^2$$

The vial used for the test is shown in Figure 5-3. The volume of the right cylinder below the neck is

$$V_{\text{vial_cylinder}} := A_{\text{vial}} \left(1 \text{ in} + \frac{7}{8} \text{ in} \right)$$

$$V_{\text{vial_cylinder}} = 24.132 \text{ ml}$$

The sample volume in the vial is

$$V_{\text{sample}} := 10 \text{ ml}$$

The sample depth is

$$D_{\text{sample}} := \frac{V_{\text{sample}}}{A_{\text{vial}}}$$

$$D_{\text{sample}} = 0.388 \text{ in}$$

$$D_{\text{liq}} := D_{\text{sample}}$$

The sample is assumed to be near equilibrium. The assumed temperature difference is

$$\Delta T_{\text{vial}} := 2 \text{ F}$$

The temperature is assumed to be

$$T_{\text{cell}} := 72 \text{ F}$$

The initial OH concentration is

$$\text{OH}_{\text{vial_init}} := .0097 \text{ M}$$

The time period between measurements is

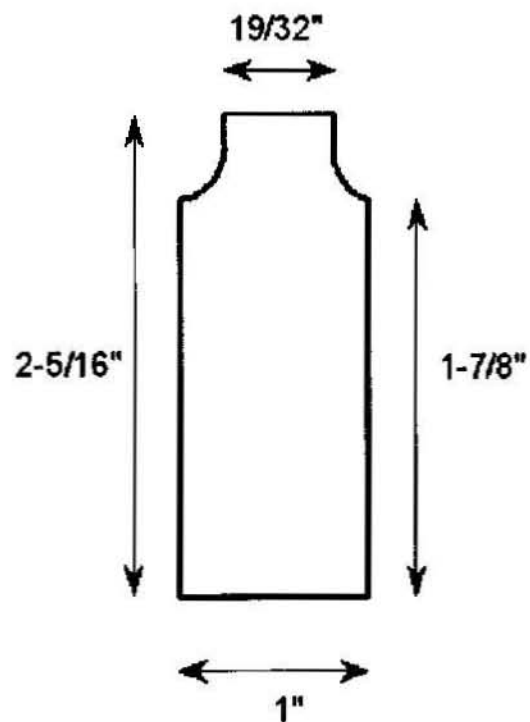
$$\Delta t_{\text{vial}} := 20 \text{ min}$$

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Figure 4-2 Scintillation Vial.





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4.3 HYDROXIDE DEPLETION RATE EVALUATION

There is a column of air above the sample in the vial. The analyses assumes that the air in the vial neck is mixed either by natural convection or from the slow stirring of the sample that occurred during the test. The CO₂ concentration of the bulk air exists in the vial bottle neck.

$$x_{\text{co2}} := 360 \text{ ppm}$$

$$\Delta T_{\text{liq}} := .5 \text{ F}$$

$$\text{CO3}_{\text{vial}} := .000001 \text{ M}$$

4.3.1 Hydroxide Depletion Rate for Period 1

Step 1 - Calculate the Liquid Side OH Mass Transfer Rate

The OH mass transfer rate on the liquid side is calculated first based upon a guess at the OH concentration at the liquid interface. The guess is revised until the OH depletion rate agrees with the liquid side OH mass transfer rate (step 3).

$$\text{OH}_{\text{i_guess}} := .000091 \cdot \text{OH}_{\text{vial}_0}$$

$$\text{OH}_{\text{liq_mass_transfer}} := \omega_{\text{OH_liq}}(\Delta T_{\text{liq}}, T_{\text{cell}}, D_{\text{sample}}, A_{\text{vial}}, \text{OH}_{\text{vial}_0}, \text{OH}_{\text{i_guess}})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

$$\text{OH}_{\text{dep}} := \omega_{\text{OH_air}}(\Delta T_{\text{vial}}, T_{\text{cell}}, D_{\text{vial}}, A_{\text{vial}}, \text{OH}_{\text{i_guess}}, \text{CO3}_{\text{vial}}, x_{\text{co2}})$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO₂ absorption rate from air is compared to the OH mass transfer rate on the liquid side. The OH interface concentration is adjusted and the three calculation steps are repeated until these numbers agree.

$$\text{OH}_{\text{liq_mass_transfer}} = 0.454 \frac{\text{mole}}{\text{yr}}$$

$$\text{OH}_{\text{dep}} = 0.456 \frac{\text{mole}}{\text{yr}}$$

The molar depletion rate is given by

$$\text{OH}_{\text{dep_calc}_1} := \frac{\text{OH}_{\text{dep}}}{V_{\text{sample}}}$$

$$\text{OH}_{\text{dep_calc}_1} = 8.673 \times 10^{-5} \frac{\text{M}}{\text{min}}$$

The measured molar depletion rate is

$$\text{OH}_{\text{dep_lab}_1} = 6.3 \times 10^{-5} \frac{\text{M}}{\text{min}}$$



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4.3.2 Hydroxide Depletion Rate for Period 2

Step 1 - Calculate the Liquid Side OH Mass Transfer Rate

The OH mass transfer rate on the liquid side is calculated first based upon a guess at the OH concentration at the liquid interface. The guess is revised until the OH depletion rate agrees with the liquid side OH mass transfer rate (step 3).

$$\text{OH}_{i_guess} := .000101 \cdot \text{OH}_{vial_1}$$

$$\text{OH}_{liq_mass_transfer} := \omega_{\text{OH}_{liq}}(\Delta T_{liq}, T_{cell}, D_{sample}, A_{vial}, \text{OH}_{vial_1}, \text{OH}_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

$$\text{OH}_{dep} := \omega_{\text{OH}_{air}}(\Delta T_{vial}, T_{cell}, D_{vial}, A_{vial}, \text{OH}_{i_guess}, \text{CO3}_{vial}, x_{\text{co2}})$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side. The OH interface concentration is adjusted and the three calculation steps are repeated until these numbers agree.

$$\text{OH}_{liq_mass_transfer} = 0.395 \frac{\text{mole}}{\text{yr}}$$

$$\text{OH}_{dep} = 0.398 \frac{\text{mole}}{\text{yr}}$$

The molar depletion rate is given by

$$\text{OH}_{dep_calc_2} := \frac{\text{OH}_{dep}}{V_{sample}}$$

$$\text{OH}_{dep_calc_2} = 7.562 \times 10^{-5} \frac{\text{M}}{\text{min}}$$

The measured molar depletion rate is

$$\text{OH}_{dep_lab_2} = 6.78 \times 10^{-5} \frac{\text{M}}{\text{min}}$$



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4.3.3 Hydroxide Depletion Rate for Period 3

Step 1 - Calculate the Liquid Side OH Mass Transfer Rate

The OH mass transfer rate on the liquid side is calculated first based upon a guess at the OH concentration at the liquid interface. The guess is revised until the OH depletion rate agrees with the liquid side OH mass transfer rate (step 3).

$$OH_{i_guess} := .000116 \cdot OH_{vial_2}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{cell}, D_{sample}, A_{vial}, OH_{vial_2}, OH_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

$$OH_{dep} := \omega_{OH_air}(\Delta T_{vial}, T_{cell}, D_{vial}, A_{vial}, OH_{i_guess}, CO3_{vial}, x_{co2})$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side. The OH interface concentration is adjusted and the three calculation steps are repeated until these numbers agree.

$$OH_{liq_mass_transfer} = 0.331 \frac{\text{mole}}{\text{yr}}$$

$$OH_{dep} = 0.332 \frac{\text{mole}}{\text{yr}}$$

The molar depletion rate is given by

$$OH_{dep_calc_3} := \frac{OH_{dep}}{V_{sample}}$$

$$OH_{dep_calc_3} = 6.31 \times 10^{-5} \frac{M}{\text{min}}$$

The measured molar depletion rate is

$$OH_{dep_lab_3} = 7 \times 10^{-5} \frac{M}{\text{min}}$$

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$$OH_{calc_1} := OH_{vial_0} - OH_{dep_calc_1} \cdot \Delta t_{vial}$$

$$OH_{calc_2} := OH_{calc_1} - OH_{dep_calc_2} \cdot \Delta t_{vial}$$

$$OH_{calc_3} := OH_{calc_2} - OH_{dep_calc_3} \cdot \Delta t_{vial}$$

$$OH_{calc} = \begin{pmatrix} 0 \\ 7.96 \times 10^{-3} \\ 6.448 \times 10^{-3} \\ 5.186 \times 10^{-3} \end{pmatrix} M$$

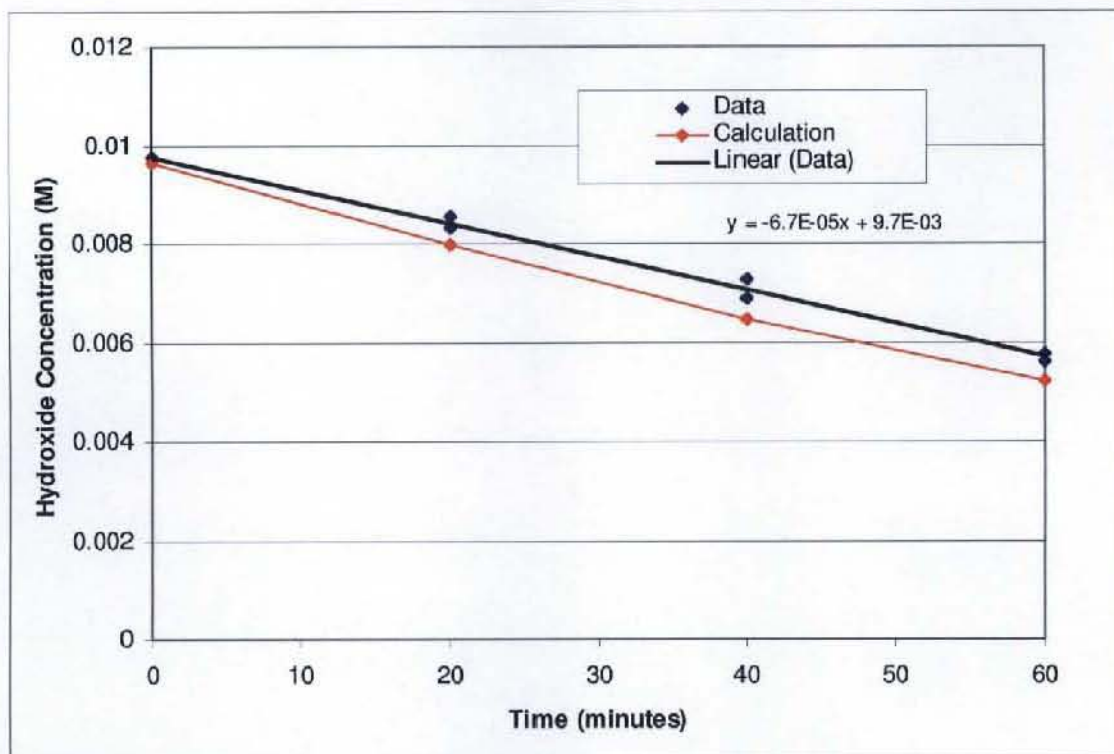


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Figure 4-3 Predicted OH Depletion Rate.



The predicted OH depletion rates are compared to data in Figure 4-3. The is reasonable agreement for each 20 minute period. The average depletion rate over the entire test period is

$$OH_{dep_data_ave} := \frac{OH_{vial_0} - OH_{vial_3}}{60min}$$

$$OH_{dep_data_ave} = 6.692 \times 10^{-5} \frac{M}{min}$$

$$OH_{dep_calc_ave} := \frac{OH_{vial_0} - OH_{calc_3}}{60min}$$

$$OH_{dep_calc_ave} = 7.515 \times 10^{-5} \frac{M}{min}$$

$$OH_{dep_data_ave} := 6.7 \cdot 10^{-5} \frac{M}{min}$$

The there is excellent agreement with the average OH depletion rate.

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5.0 DATA COMPARISON WITH VAPOR SPACE SHMS DATA**5.1 TANK AY-102**

The OH and waste volume data is shown in Figure 5-1.

$$V_{waste_1} := 828000 \text{ gal}$$

$$V_{waste_2} := 467000 \text{ gal}$$

$$V_{solids} := 19 \text{ in} \cdot A_{tank}$$

The supernatant volume is

$$V_{ay2sup_1} := V_{waste_1} - V_{solids}$$

$$V_{ay2sup_2} := V_{waste_2} - V_{solids}$$

$$\Delta T_{ay2} := \Delta T_{hanford_8}$$

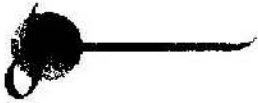
The initial OH concentration (Figure 5-1) is

$$OH_{ay2_1} := .061 \text{ M}$$

$$OH_{ay2_2} := .58 \text{ M}$$

$$OH_{ay2_3} := .082 \text{ M}$$

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5.1.1 Period 1

$$Q_{ay2} := 425 \text{ cfm}$$

$$T_{sup} := T_{sup_ay2}$$

$$OH_{data} := OH_{ay2_i}$$

$$CO3_{ay2} := \frac{20000 \frac{\text{mole}}{\text{yr}} \cdot 18 \text{ yr}}{V_{ay2sup_1}}$$

$$CO3_{ay2} = 0.123 \text{ M}$$

$$\Delta T_{liq} := 0 \text{ F}$$

$$D_{liq} := 4 \text{ in}$$

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$$Q := Q_{ay2}$$

$$T_{sup} := T_{sup_ay2}$$

$$CO3_{bulk} := CO3_{ay2}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .008 \cdot OH_{data}$$

$$CO3_{i_guess} := 2.9 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.356 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 291 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{ay2}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 290.692 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 4.088 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 3.916 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 2.079 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.958 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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$$x_{\text{co2_pnnl}} := 400 \text{ ppm}$$

The carbon dioxide absorption rate based on the Hanford OH concentration data is

$$F_{\text{ay2}_1} := \frac{\frac{\text{OH}_{\text{dep}}}{2}}{x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q}$$

$$F_{\text{ay2}_1} = 0.193$$

$$C_{\text{co2}_1} := x_{\text{co2_pnnl}} \cdot (1 - F_{\text{ay2}_1})$$

$$C_{\text{co2}_1} = 322.991 \text{ ppm}$$

$$i_{\text{data}} := 23$$

$$\text{OH}_{\text{depcalc}_{i_{\text{data}}}} := \text{OH}_{\text{dep}}$$

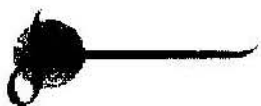
$$\text{CO2}_{\text{data}} := 299 \text{ ppm}$$

$$\text{OH}_{\text{depdata}_{i_{\text{data}}}} := 2 \left(1 - \frac{\text{CO2}_{\text{data}}}{x_{\text{co2_pnnl}}} \right) \cdot x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dephobbs}_{i_{\text{data}}}} := 2 x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q \cdot F_{\text{hobbs}}(\text{OH}_{\text{data}})$$

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5.1.2 Period 2

The analyses for this period was done in Section 3.1.7.

$$F_{ay2} := \frac{\frac{OH_{depcalc_g}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent_g}}$$

$$F_{ay2} = 0.493$$

$$C_{co2_ay2} := x_{co2_pnnl} \cdot (1 - F_{ay2})$$

$$C_{co2_ay2} = 202.692 \text{ ppm}$$

$$i_{data} := 24$$

$$OH_{depdata_{i_{data}}} := OH_{depcalc_g}$$

$$CO2_{data} := 144 \text{ ppm}$$

$$OH_{depdata_{i_{data}}} := \left[\left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \right] \cdot 2$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs_{i_{data}}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$



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5.1.3 Period 3

$$OH_{data} := OH_{ay2_3}$$

$$Q := Q_{ay2}$$

$$T_{sup} := T_{sup_{ay2}}$$

$$CO3_{bulk} := CO3_{ay2}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .0065 \cdot OH_{data}$$

$$CO3_{i_guess} := 2.9 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.356 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 258 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{ay2}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 260.757 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 5.504 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 5.608 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 2.079 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 2.804 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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$$x_{\text{co2_pnnl}} := 400 \text{ ppm}$$

The carbon dioxide absorption rate based on the Hanford OH concentration data is

$$F_{\text{ay2}_3} := \frac{\text{OH}_{\text{dep}}}{x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q}$$

$$F_{\text{ay2}_3} = 0.276$$

$$C_{\text{co2}_3} := x_{\text{co2_pnnl}} (1 - F_{\text{ay2}_3})$$

$$C_{\text{co2}_3} = 289.73 \text{ ppm}$$

$$i_{\text{data}} := 25$$

$$\text{OH}_{\text{depcalc}_{i_{\text{data}}}} := \text{OH}_{\text{dep}}$$

$$\text{CO2}_{\text{data}} := 299 \text{ ppm}$$

$$\text{OH}_{\text{depxdata}_{i_{\text{data}}}} := 2 \left(1 - \frac{\text{CO2}_{\text{data}}}{x_{\text{co2_pnnl}}} \right) \cdot x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dephobbs}_{i_{\text{data}}}} := 2 x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q \cdot F_{\text{hobbs}}(\text{OH}_{\text{data}})$$

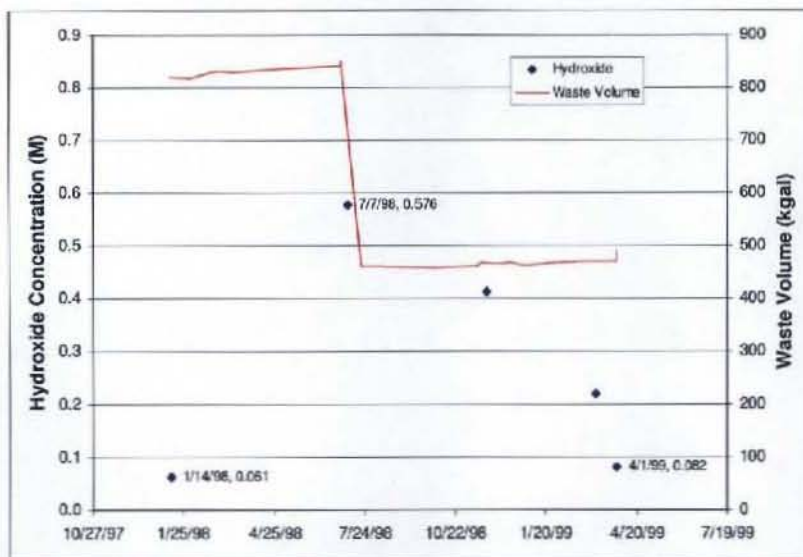
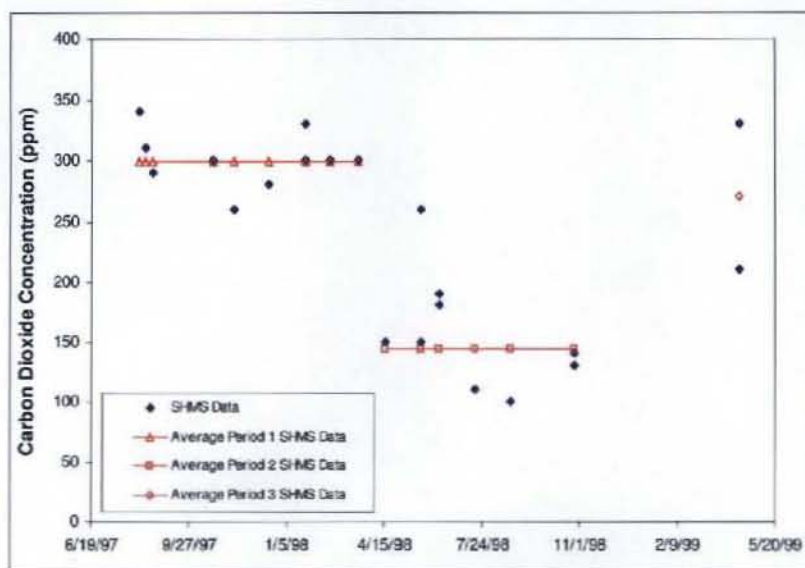


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Figure 5-1. AY-102 Level and OH Data

Figure 5-2. AY-102 CO₂ Data.

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5.2 AZ-101

The analyses presented in Section 3.1.8 is used.

$$OH_{dep} := OH_{dcp_hanford_ogden} \cdot V_{sup}$$

$$F_{az1} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent}}$$

$$F_{az1} = 0.865$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{az1})$$

$$C_{co2} = 53.916 \text{ ppm}$$

$$i_{data} := 26$$

$$OH_{depcalc_{i_{data}}} := OH_{dcp}$$

$$CO2_{data} := 97 \text{ ppm}$$

$$OH_{depdata_{i_{data}}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs_{i_{data}}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{hanford_data_8})$$

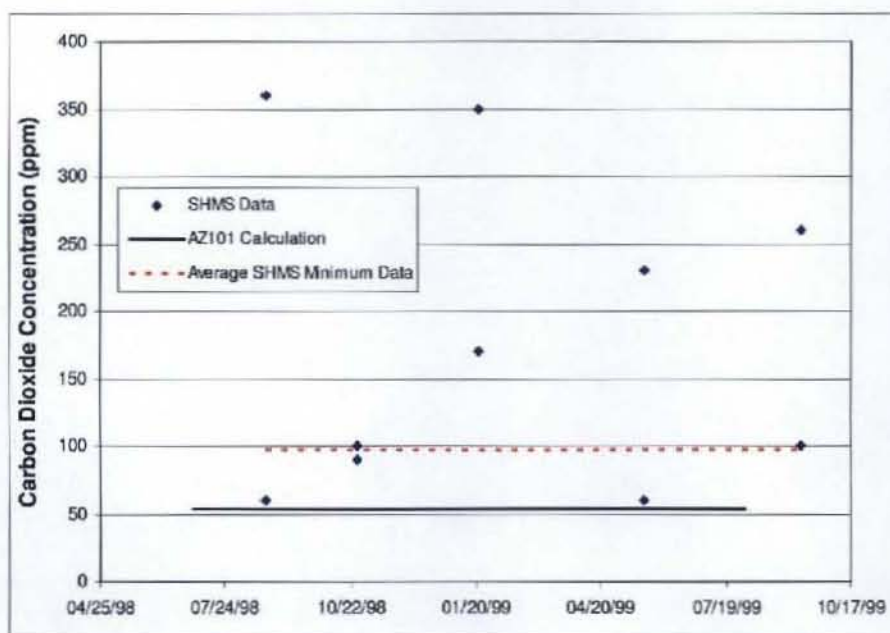


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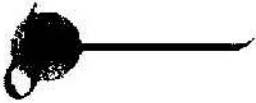
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Figure 5-3. AZ-101 CO₂ Data.



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5.3 TANK AZ-102

Analyses parameters presented in Section 3.1.9.

$$Q := Q_{vent_{10}}$$

$$T_{sup} := T_{sup_{az2}}$$

$$\Delta T_{az2} := \Delta T_{hanford_{10}}$$

$$OH_{data} := 0.02M$$

$$\Delta T_{liq} := 0F$$

$$D_{liq} := 4in$$

$$CO3_{az2} := \frac{6000 \frac{mole}{yr} \cdot 20yr}{V_{sup_{10}}}$$

$$CO3_{az2} = 0.037M$$

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$$Q := Q_{vent_{10}}$$

$$T_{sup} := T_{sup_{az2}}$$

$$CO3_{bulk} := CO3_{az2}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .01194 \cdot OH_{data}$$

$$CO3_{i_guess} := 2.23 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.082 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 268.5 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{az2}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 269.35 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.335 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.229 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 4.06 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 6.146 \times 10^3 \frac{\text{mole}}{\text{yr}}$$



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$$\frac{OH_{dep}}{2} = 6.148 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$F_{az2_2} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{az2_2} = 0.252$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{az2_2})$$

$$C_{co2} = 299.277 \text{ ppm}$$

$$i_{data} := 27$$

$$OH_{depcalc, i_{data}} := OH_{dep}$$

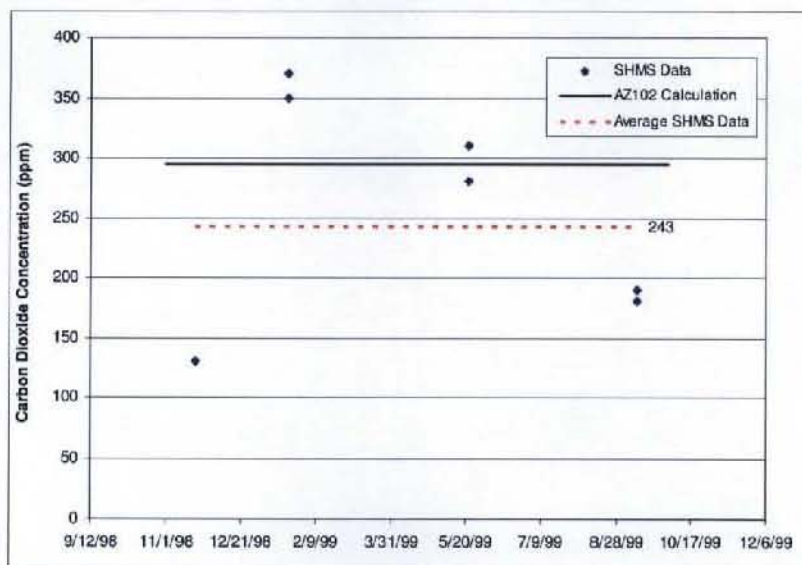
$$CO2_{data} := 243 \text{ ppm}$$

$$OH_{depdata, i_{data}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs, i_{data}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{hanford_data_y})$$

Figure 5-4. AZ-102 1999 Carbon Dioxide Data.



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5.4 AWF Ventilation Data

5.4.1 TANK AY-101 August 2000

Parameters taken from Section 3.1.11.

$$Q := Q_{vent_{12}}$$

$$Q_{ay1} := Q$$

$$T_{sup} := T_{sup_{ay1}}$$

$$\Delta T_{ay1} := \Delta T_{hanford_{12}}$$

$$OH_{data} := 0.00006M$$

$$\Delta T_{liq} := 0F$$

$$D_{liq} := 4in$$

$$CO3_{ay1} := \frac{15000 \frac{mole}{yr} \cdot 15yr}{V_{sup_{12}}}$$

$$CO3_{ay1} = 0.69 M$$



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Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .999999 \cdot OH_{data}$$

$$CO3_{i_guess} := 1.0001 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.037 M$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 359.9 ppm$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{ay1}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 360.499 ppm$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 4.054 \times 10^{-5} \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = -225.781 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 0.33 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = -112.891 \frac{\text{mole}}{\text{yr}}$$

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$$\frac{OH_{dep}}{2} = -112.891 \frac{\text{mole}}{\text{yr}}$$

$$F_{ay1} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{ay1} = -1.387 \times 10^{-3}$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{ay1})$$

$$C_{co2} = 400.555 \text{ ppm}$$

$$OH_{dep_{ay1}} := OH_{dep}$$

The depletion rate based upon the Hobbs model is

$$OH_{dep_{hobbs_{ay1}}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

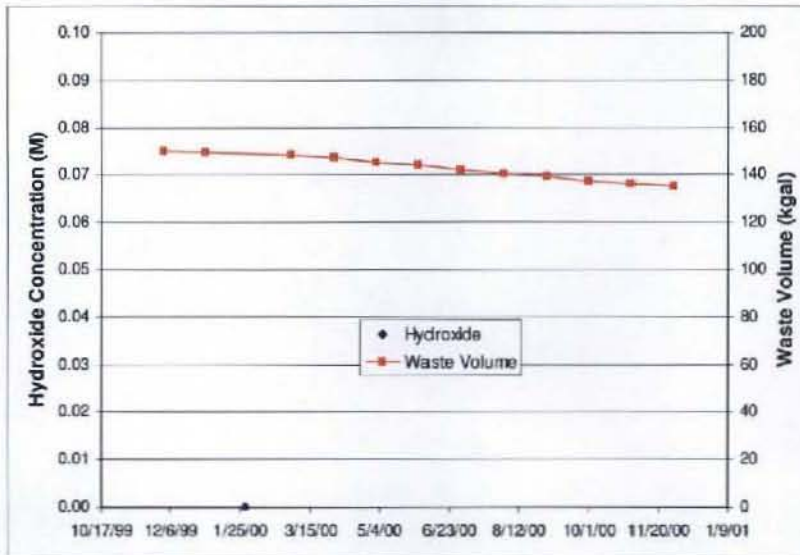


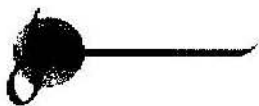
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Figure 5-5. AY-101 Carbon Dioxide Data.





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5.4.2 TANK AY-102 August 2000

Parameters taken from Section 3.1.7.

$$Q := Q_{vent,7}$$

$$Q_{ay2} := Q$$

$$T_{sup} := T_{sup_ay2}$$

$$\Delta T_{ay2} := \Delta T_{hanford,7}$$

$$OH_{data} := 0.012M$$

$$\Delta T_{liq} := 0F$$

$$D_{liq} := 4in$$

$$CO3_{ay2} := \frac{15000 \frac{\text{mole}}{\text{yr}} \cdot 15yr}{V_{sup,7}}$$

$$CO3_{ay2} = 0.122M$$



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Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .016 \cdot OH_{data}$$

$$CO3_{i_guess} := 1.905 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.07 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 347 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{hanford}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 347.204 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 7.978 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 7.226 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 2.987 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 3.613 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

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$$\frac{OH_{dep}}{2} = 3.616 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$F_{ay2} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{ay2} = 0.036$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{ay2})$$

$$C_{co2} = 385.782 \text{ ppm}$$

$$OH_{dep_{ay2}} := OH_{dep}$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs_{ay2}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

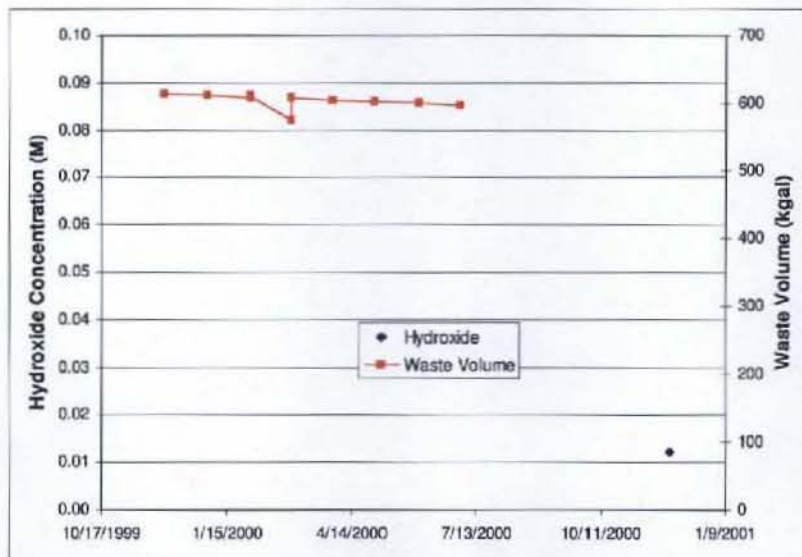


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Figure 5-6. AY-102 Carbon Dioxide Data.



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5.4.3 AZ-101 August 2000

Parameters taken from Section 3.1.9.

$$OH_{dep} := OH_{dep_hanford_ogden_9} \cdot V_{sup_9}$$

$$F_{az1} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent_9}}$$

$$F_{az1} = 0.865$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{az1})$$

$$C_{co2} = 53.916 \text{ ppm}$$

$$OH_{dep_{az1}} := OH_{dep}$$

$$Q_{az1} := Q_{vent_9}$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs_{az1}} := 2x_{co2_amb} \cdot C_{air} \cdot Q_{az1} \cdot F_{hobbs}(OH_{hanford_data_9})$$

5.4.4 AZ-102 August 2000

Results from Section 5.3 are used here.

$$OH_{dep} := OH_{depcalc_27}$$

$$F_{az2} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q_{vent_{10}}}$$

$$F_{az2} = 0.252$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{az2})$$

$$C_{co2} = 299.277 \text{ ppm}$$

$$OH_{dep_{az2}} := OH_{dep}$$

$$Q_{az2} := Q_{vent_{10}}$$

The depletion rate based upon the Hobbs model is

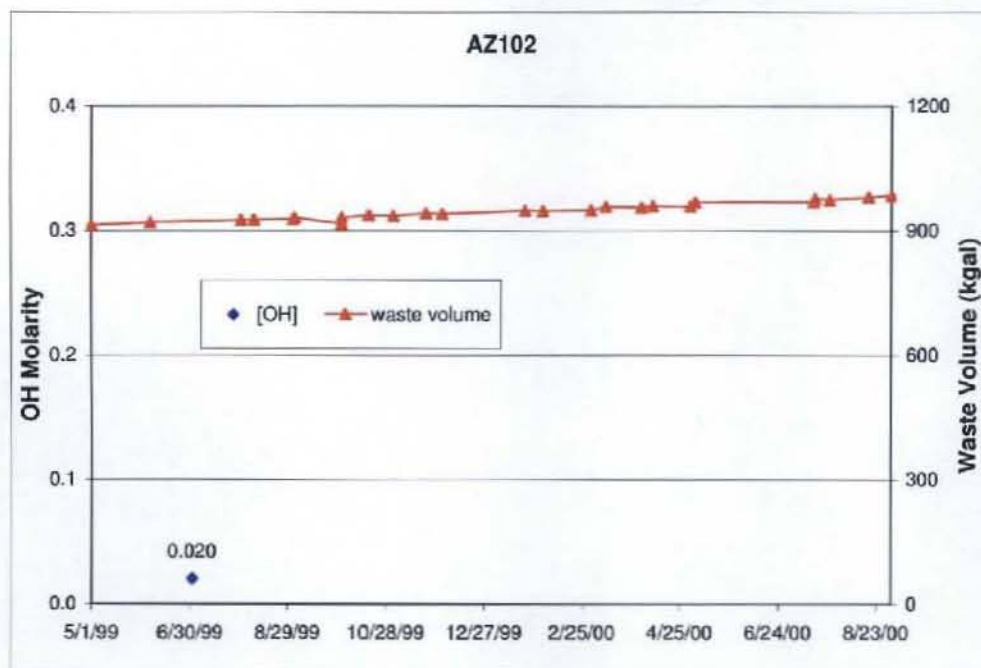
$$OH_{dephobbs_{az2}} := 2x_{co2_amb} \cdot C_{air} \cdot Q_{az2} \cdot F_{hobbs}(0.02M)$$



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Figure 5-7. AZ-102 Carbon Dioxide Data.



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5.4.5 AWF Vent Results

$$Q_{awf} := Q_{ay1} + Q_{ay2} + Q_{az1} + Q_{az2}$$

$$i_{data} := 28$$

$$OH_{depcalc, i_{data}} := OH_{dep_{ay1}} + OH_{dep_{ay2}} + OH_{dep_{az1}} + OH_{dep_{az2}}$$

$$OH_{depcalc, i_{data}} = 8.101 \times 10^4 \frac{\text{mol}}{\text{yr}}$$

$$F_{awf} := \frac{OH_{depcalc, i_{data}}}{2 \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{awf}}$$

$$F_{awf} = 0.167$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{awf})$$

$$C_{co2} = 333.372 \text{ ppm}$$

$$OH_{dephobbs, i_{data}} := OH_{dephobbs_{ay1}} + OH_{dephobbs_{ay2}} + OH_{dephobbs_{az1}} + OH_{dephobbs_{az2}}$$

$$CO2_{data} := 325 \text{ ppm}$$

$$OH_{depdata, i_{data}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{awf} \cdot 2$$

$$OH_{depdata, i_{data}} = 9.119 \times 10^4 \frac{\text{mol}}{\text{yr}}$$

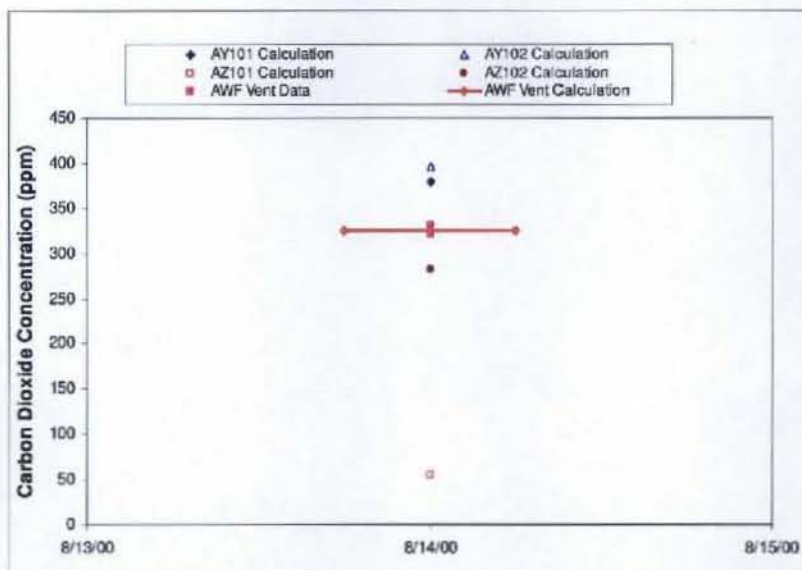


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Figure 5-8. AWF Carbon Dioxide Data.



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5.5 TANK SY-101

$$Q_{sy1} := 333 \text{ cfm}$$

$$T_{sup_sy1} := 80 \text{ F}$$

The vapor space/supernatant temperature difference for Tank SY-103 is used since these data are not available for SY-101. The two tanks have about the same heat load since the ventilation flow rates and supernatant temperatures are about the same.

$$\Delta T_{sy1} := 2 \text{ F}$$

$$V_{saltcake} := 275 \text{ kgal}$$

$$V_{sup_aw1} := 736 \text{ kgal}$$

$$OH_{data} := 1.55 \text{ M}$$

$$\Delta T_{liq} := 0 \text{ F}$$

$$CO3_{sy1} := \frac{2500 \frac{\text{mole}}{\text{yr}} \cdot 8 \text{ yr}}{V_{sup_aw1}}$$

$$CO3_{sy1} = 7.179 \times 10^{-3} \text{ M}$$

$$L_{crust_sy1} := 16 \text{ in}$$



$$Q := Q_{sy1}$$

$$T_{sup} := T_{sup_sy1}$$

$$CO_2^{bulk} := CO_2^{sy1}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .00088 \cdot OH_{data}$$

$$CO_2_{i_guess} := 490 \cdot CO_2^{bulk}$$

$$CO_2_{i_guess} = 3.518M$$

$$OH_{liq_mass_transfer} := \omega_{OH_{liq}}(\Delta T_{liq}, T_{sup}, L_{crust_sy1}, E \cdot A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO_2_{mass_transfer} := \omega_{CO_2}(\Delta T_{liq}, T_{sup}, L_{crust_sy1}, E \cdot A_{tank}, CO_2^{bulk}, CO_2_{i_guess})$$

$$CO_2_{mass_transfer_liq} := \omega_{CO_2_liq}(\Delta T_{liq}, T_{sup}, L_{crust_sy1}, E \cdot A_{tank}, OH_{data}, OH_{i_guess}, CO_2^{bulk}, CO_2_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO₂ mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 343ppm$$

$$OH_{dep} := \omega_{OH_{air}}(\Delta T_{sy1}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO_2_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO₂ concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 346.015 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO₂ absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 5.232 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO_2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 6.193 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO₂ Mass Transfer Rate

The CO₂ mass transfer rate should be half the surface OH Depletion rate.

$$CO_2_{mass_transfer} = 1.566 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 3.096 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

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$$\frac{OH_{dep}}{2} = 3.096 \times 10^{-3} \frac{\text{mole}}{\text{yr}}$$

$$F_{sy1} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{sy1} = 0.039$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{sy1})$$

$$C_{co2} = 384.461 \text{ ppm}$$

$$i_{data} := 29$$

$$OH_{depleaic, i_{data}} := OH_{dep}$$

$$CO2_{data} := 360 \text{ ppm}$$

$$OH_{depldata, i_{data}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

$$OH_{deplsy1} := OH_{dep}$$

$$CO2_{sy1} := C_{co2}$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs, i_{data}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$



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Figure 5-9. SY-101 Carbon Dioxide Data.

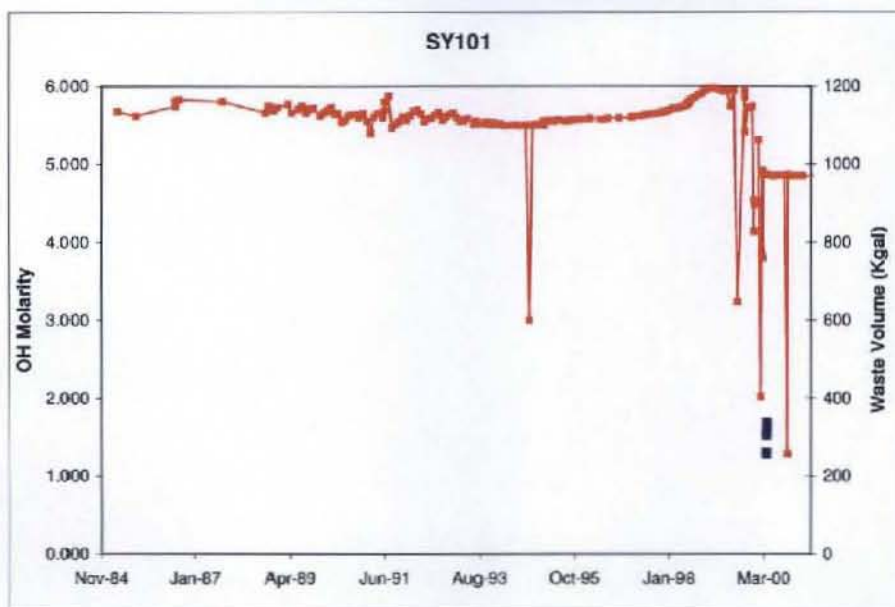
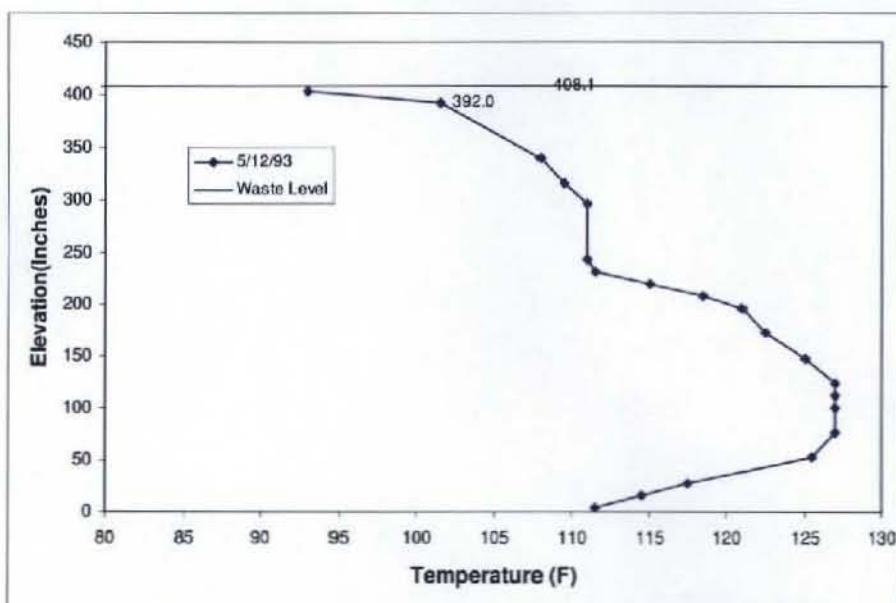


Figure 5-10. SY-101 Waste Temperature Profile.

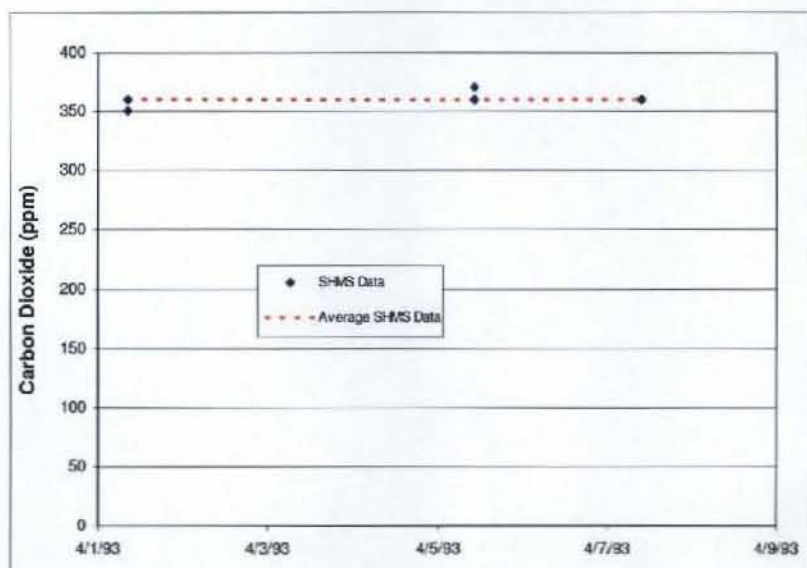




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Figure 5-11. SY-101 Carbon Dioxide Data.

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5.6 TANK SY-102

5.6.1 Tank SY-102 Period 1

$$Q_{sy2} := 330 \text{ cfm}$$

$$T_{sup_sy2} := 65 \text{ F}$$

$$\Delta T_{sy2} := .1 \text{ F}$$

$$OH_{sy2_1} := 0.074 \text{ M}$$

$$OH_{sy2_2} := .182 \text{ M}$$

$$V_{sy2} := 747 \text{ kgal}$$

$$V_{sy2solids} := 145 \text{ kgal}$$

$$V_{supsy2} := V_{sy2} - V_{sy2solids}$$

$$\Delta T_{liq} := 0 \text{ F}$$

$$D_{liq} := 4 \text{ in}$$

$$CO3_{sy2} := \frac{25000 \frac{\text{mole}}{\text{yr}} \cdot 20 \text{ yr}}{V_{supsy2}}$$

$$CO3_{sy2} = 0.219 \text{ M}$$

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$$OH_{data} := OH_{sy2}$$

$$Q := Q_{sy2}$$

$$T_{sup} := T_{sup_sy2}$$

$$CO3_{bulk} := CO3_{sy2}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .0081 \cdot OH_{data}$$

$$CO3_{i_guess} := 1.7 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.373 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 265 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{sy2}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 264.066 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 4.959 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 4.209 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.371 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 2.105 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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$$F_{sy2_1} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{sy2_1} = 0.266$$

$$C_{co2} := x_{co2_pnrl} \cdot (1 - F_{sy2_1})$$

$$C_{co2} = 293.406 \text{ ppm}$$

$$i_{data} := 30$$

$$OH_{depcalc_{i_{data}}} := OH_{dep}$$

$$CO2_{data} := 297 \text{ ppm}$$

$$OH_{depdata_{i_{data}}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnrl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs_{i_{data}}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$



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5.6.2 Period 2

$$OH_{data} := OH_{sy2}$$

$$\Delta T_{sy2} := 1F$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .03 \cdot OH_{data}$$

$$CO3_{i_guess} := 4 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.878 M$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 103ppm$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{sy2}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 104.714 ppm$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.193 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.12 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 5.874 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 5.601 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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$$F_{sy2_2} := \frac{OH_{dep}}{2 \cdot x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{sy2_2} = 0.709$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{sy2_2})$$

$$C_{co2} = 116.349 \text{ ppm}$$

$$i_{data} := 31$$

$$OH_{depcalc_{i_{data}}} := OH_{dep}$$

$$CO2_{data} := 122 \text{ ppm}$$

$$OH_{depdata_{i_{data}}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

$$OH_{dep_{sy2}} := OH_{dep}$$

$$CO2_{sy2} := C_{co2}$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs_{i_{data}}} := 2 \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$



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Figure 5-12. SY-102 Carbon Dioxide Data.

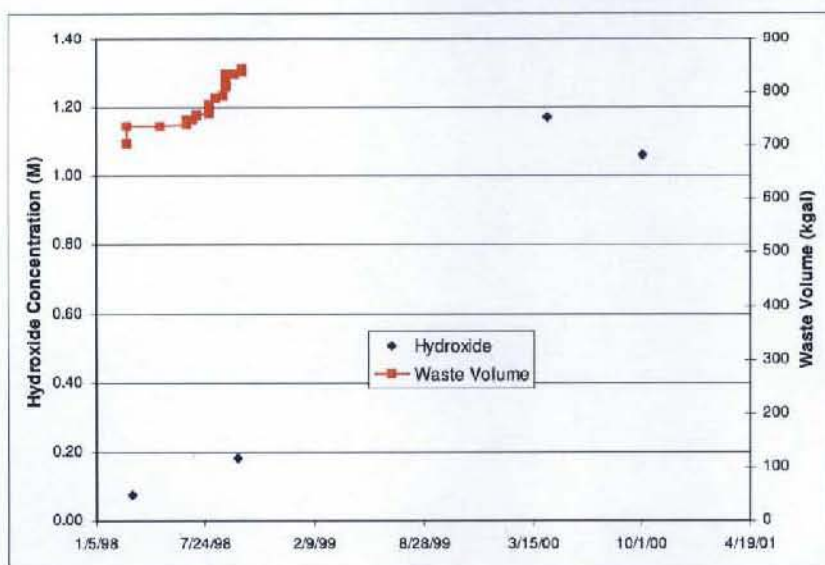
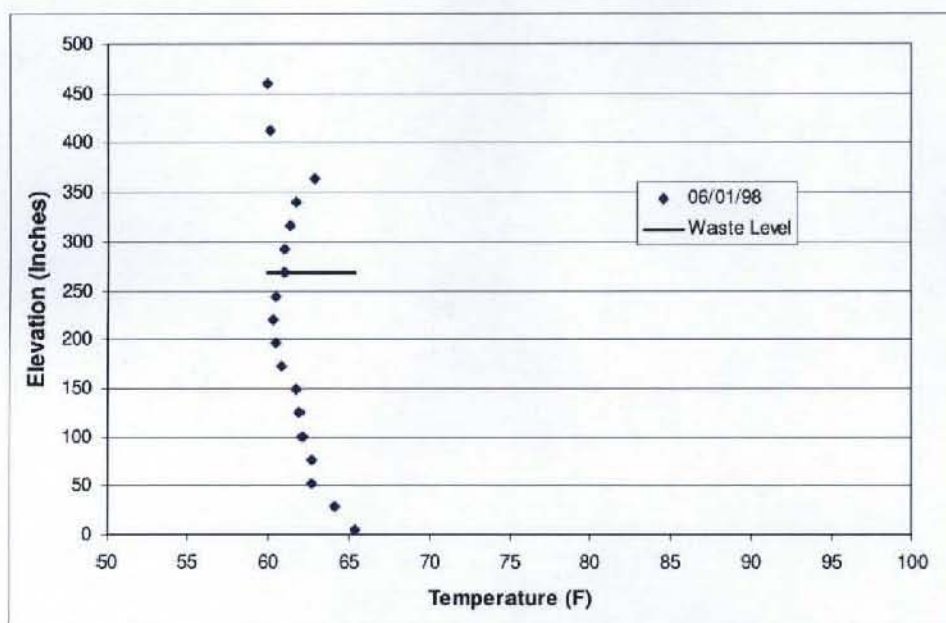


Figure 5-13. SY-102 Waste Temperature Profile.

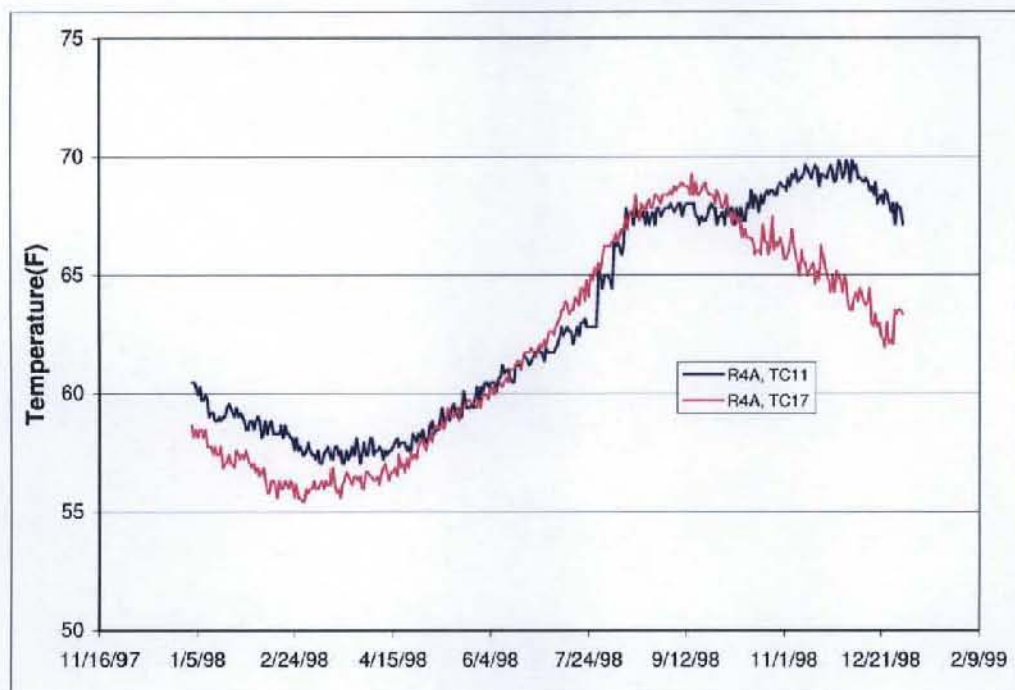




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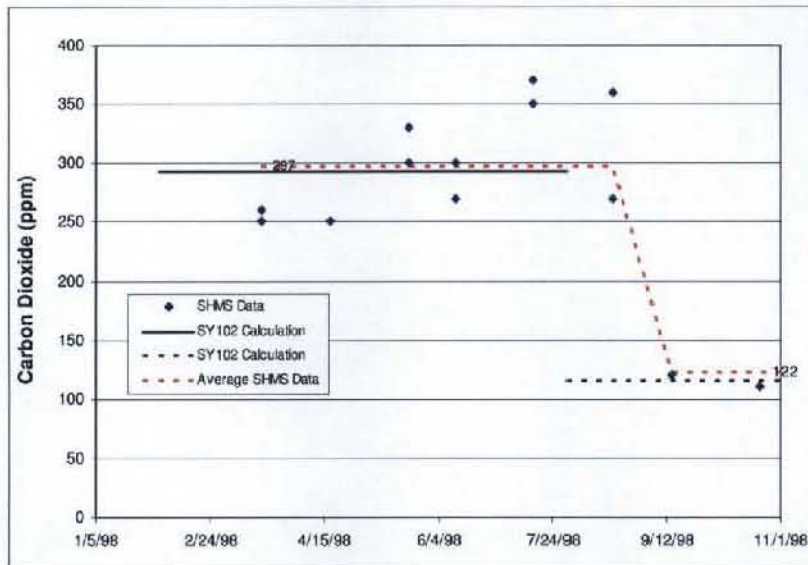
Figure 5-14. SY-102 Vapor Space and Supernatant Temperatures.



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Figure 5-15. SY-102 Carbon Dioxide Data.

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5.7 TANK SY-103

$$Q_{sy3} := 333 \text{ cfm}$$

$$T_{sup_sy3} := 80 \text{ F}$$

$$\Delta T_{sy3} := 2 \text{ F}$$

$$OH_{data} := 1.72 \text{ M}$$

$$V_{sy3} := 747 \text{ kgal}$$

$$z_{sy3} := \frac{V_{sy3}}{A_{tank}}$$

$$z_{sy3} = 271.242 \text{ in}$$

$$V_{saltcake_sy3} := 342 \text{ kgal}$$

$$V_{sup_sy3} := \frac{V_{sy3} - V_{saltcake_sy3}}{2}$$

$$\Delta T_{liq} := 0 \text{ F}$$

$$L_{crust_sy3} := 26 \text{ in}$$

$$E := .2$$

$$CO3_{sy3} := \frac{5000 \frac{\text{mole}}{\text{yr}} \cdot 10 \text{ yr}}{V_{sup_sy3}}$$

$$CO3_{sy3} = 0.065 \text{ M}$$



5.7.1 Period 2

$$Q = Q_{sy3}$$

$$T_{sup} := T_{sup_sy3}$$

$$CO3_{bulk} := CO3_{sy3}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .0011 \cdot OH_{data}$$

$$CO3_{i_guess} := 80 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 5.218M$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, L_{crust_sy3}, E \cdot A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, L_{crust_sy3}, E \cdot A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, L_{crust_sy3}, E \cdot A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 285 \cdot ppm$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{sy3}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 285.432 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.572 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 3.302 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.415 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.651 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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$$F_{sy3} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{sy3} = 0.207$$

$$C_{co2} := x_{co2_pnl} \cdot (1 - F_{sy3})$$

$$C_{co2} = 317.146 \text{ ppm}$$

$$i_{data} := 32$$

$$OH_{dep_{calc, i_{data}}} := OH_{dep}$$

$$CO2_{data} := 335 \text{ ppm}$$

$$OH_{dep_{data, i_{data}}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

The depletion rate based upon the Hobbs model is

$$OH_{dep_{hobbs, i_{data}}} := 2 \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$



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5.7.2 Period 1

$$Q := 0.33Q_{sy3}$$

$$T_{sup} := T_{sup_sy3}$$

$$CO3_{bulk} := CO3_{sy3}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .0015 \cdot OH_{data}$$

$$CO3_{i_guess} := 72 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 4.696 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, L_{crust_sy3}, E \cdot A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, L_{crust_sy3}, E \cdot A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, L_{crust_sy3}, E \cdot A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 149 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{sy3}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 146.532 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.57 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 3.119 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.272 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.56 \times 10^4 \frac{\text{mole}}{\text{yr}}$$



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$$F_{sy3} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

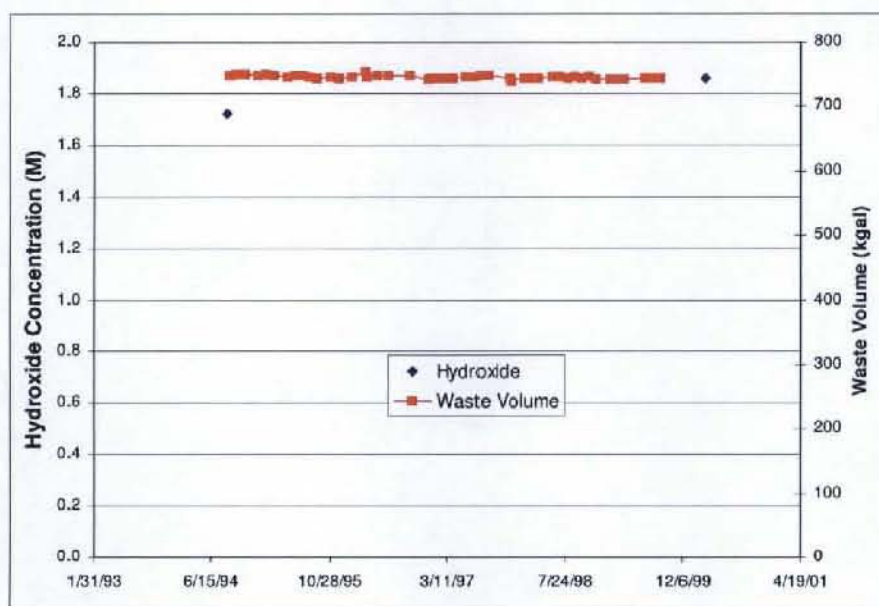
$$F_{sy3} = 0.593$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{sy3})$$

$$C_{co2} = 162.813 \text{ ppm}$$

$$CO2_{sy3b} := C_{co2}$$

Figure 5-16. SY-103 Waste Volume and OH Concentration.





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Figure 5-17. SY-103 Waste Temperature Profiles.

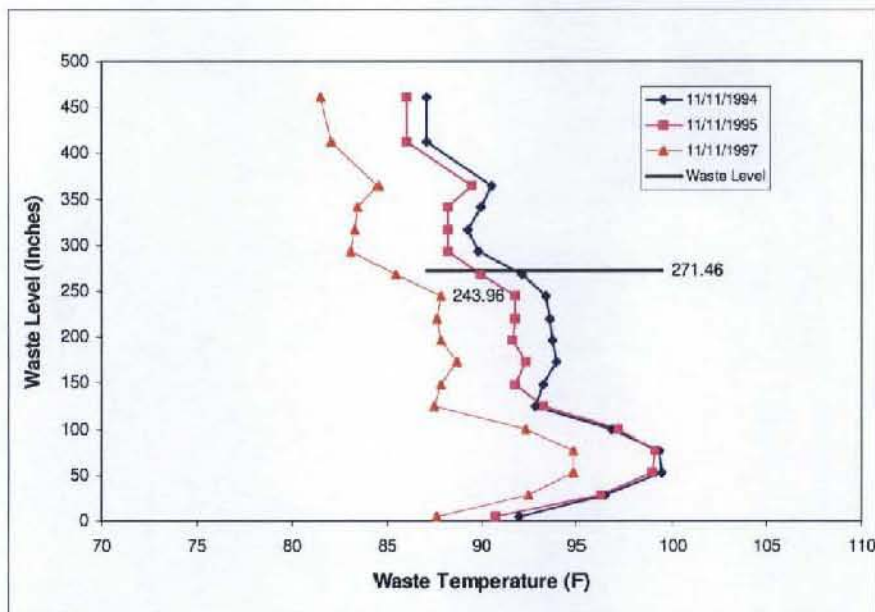
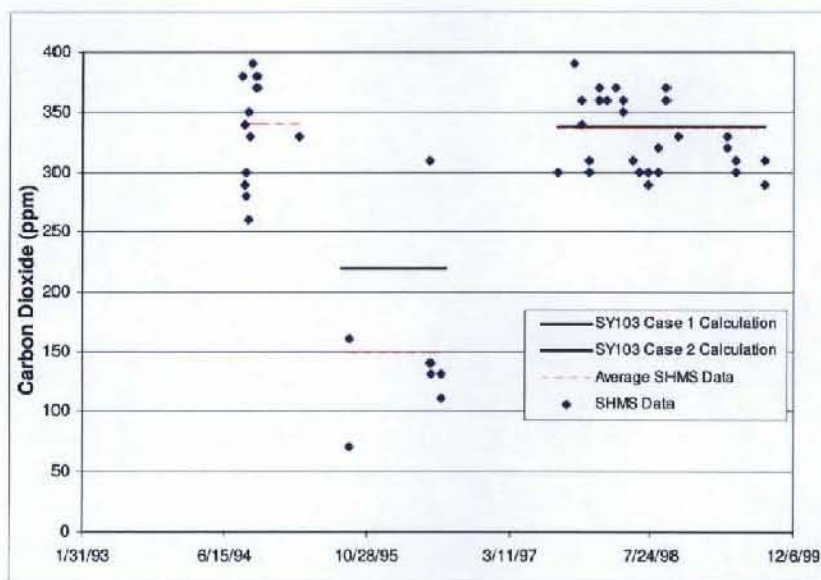


Figure 5-18. SY-103 Carbon Dioxide Data.





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5.8 SY-Farm Ventilation Data

5.8.1 SY-101

$$Q := Q_{sy1}$$

$$T_{sup} := T_{sup_sy1}$$

$$CO3_{bulk} := CO3_{sy1}$$

$$\Delta T_{sy1} := .1F$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .93 \cdot OH_{data}$$

$$CO3_{i_guess} := 90 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.646 M$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 167 ppm$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{sy1}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 168.902 ppm$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 8.135 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 8.462 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 5.701 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 4.231 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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$$F_{sy2_1} := \frac{OH_{dep}}{2 \cdot x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{sy2_1} = 0.531$$

$$C_{co2} := x_{co2_pna1} \cdot (1 - F_{sy2_1})$$

$$C_{co2} = 187.669 \text{ ppm}$$

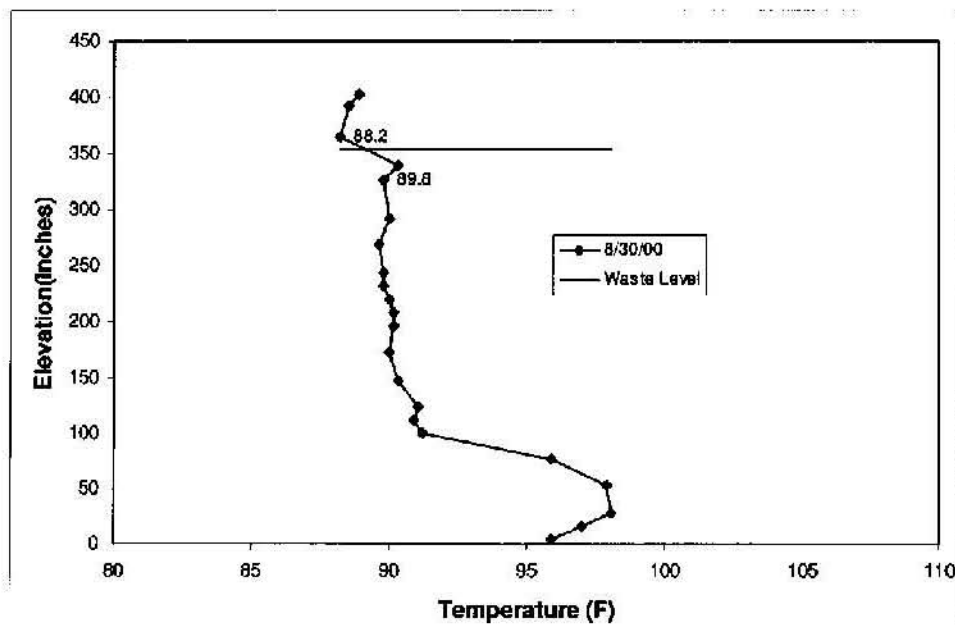
$$OH_{dep_{sy1}} := OH_{dep}$$

$$CO2_{sy1} := C_{co2}$$

The depletion rate based upon the Hobbs model is

$$OH_{hobbs_{sy1}} := 2 \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

Figure 5-19. SY-101 8/3/00 Waste Temperature Profile.





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5.8.2 SY-102

$$OH_{data} := \frac{1.17M + 1.06M}{2}$$

$$\Delta T_{sy2} := 1F$$

$$T_{sup} := T_{sup_sy2}$$

$$CO3_{bulk} := CO3_{sy2}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .03 \cdot OH_{data}$$

$$CO3_{i_guess} := 3 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.646M$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 103ppm$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{sy2}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 93.637 ppm$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 7.307 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.179 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 3.807 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 5.897 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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$$F_{sy2} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{sy2} = 0.74$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{sy2})$$

$$C_{co2} = 104.041 \text{ ppm}$$

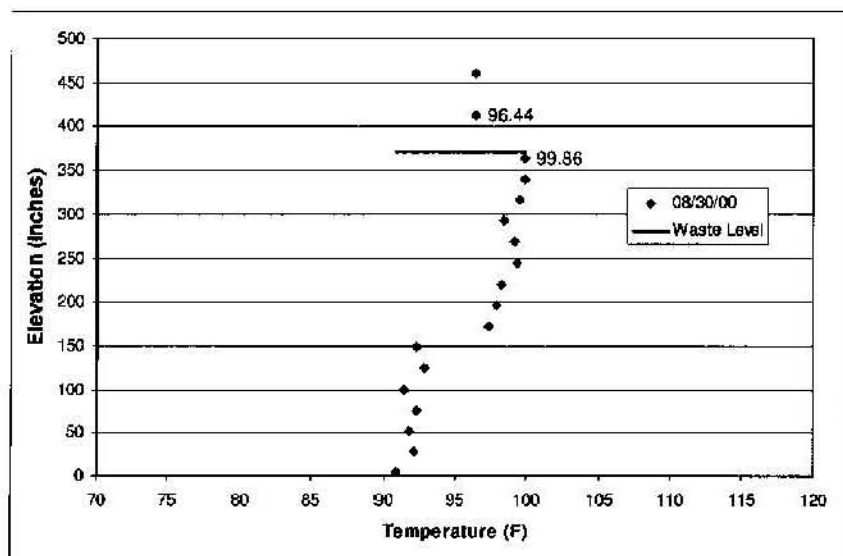
$$OH_{dep_{sy2}} := OH_{dep}$$

$$CO2_{sy2} := C_{co2}$$

The depletion rate based upon the Hobbs model is

$$OH_{hobbs_{sy2}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

Figure 5-20. SY-102 8/3/00 Waste Temperature Profile.





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5.8.3 SY-103

$$OH_{data} := 1.86M$$

$$\Delta T_{sy3} := 2.5F$$

$$Q := Q_{sy3}$$

$$T_{sup} := T_{sup_sy3}$$

$$CO3_{bulk} := CO3_{sy3}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .0011 \cdot OH_{data}$$

$$CO3_{i_guess} := 80 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 5.218M$$

$$OH_{liq_mass_transfer} := \omega_{OH_{liq}}(\Delta T_{liq}, T_{sup}, L_{crust_sy3}, E \cdot A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, L_{crust_sy3}, E \cdot A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, L_{crust_sy3}, E \cdot A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 255 \cdot ppm$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{sy3}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 253.54 \cdot ppm$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.863 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 4.714 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.415 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 2.357 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

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$$F_{sy2_3} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{sy2_3} = 0.296$$

$$C_{co2} := x_{co2_ppm} \cdot (1 - F_{sy2_3})$$

$$C_{co2} = 281.711 \text{ ppm}$$

$$OH_{dep_{sy3}} := OH_{dep}$$

$$CO2_{sy3} := C_{co2}$$

The depletion rate based upon the Hobbs model is

$$OH_{hobbs_{sy3}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$



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5.8.4 SY Farm Vent Evaluation

$$Q_{sy} := 3Q_{sy1}$$

$$i_{data} := 33$$

$$OH_{depalc, i_{data}} := OH_{dep_{sy1}} + OH_{dep_{sy2}} + OH_{dep_{sy3}}$$

$$OH_{depalc, i_{data}} = 2.497 \times 10^5 \frac{\text{mol}}{\text{yr}}$$

$$OH_{dephobbs, i_{data}} := OH_{hobbs_{sy1}} + OH_{hobbs_{sy2}} + OH_{hobbs_{sy3}}$$

$$CO2_{sy} := \frac{CO2_{sy1} + CO2_{sy2} + CO2_{sy3}}{3}$$

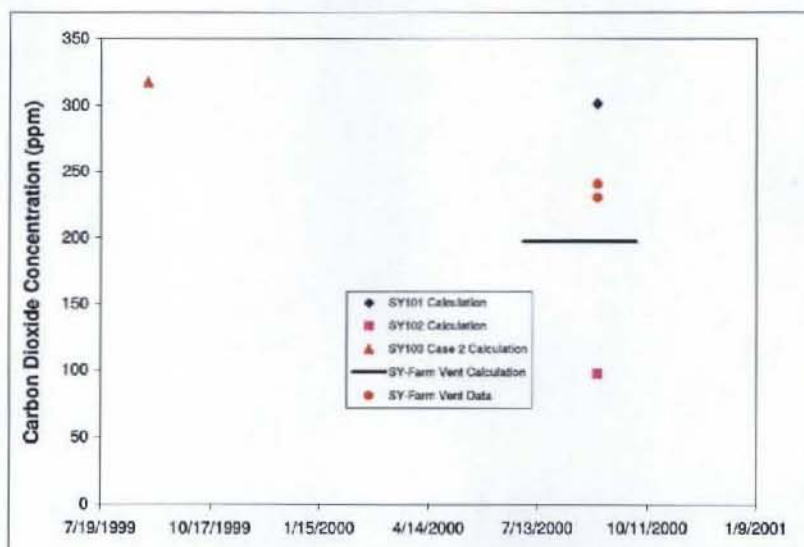
$$CO2_{sy} = 191.14 \text{ ppm}$$

$$CO2_{data} := 240 \text{ ppm}$$

$$OH_{depdata, i_{data}} := \left(1 - \frac{CO2_{data}}{X_{co2_pnnl}} \right) \cdot X_{co2_amb} \cdot C_{air} \cdot Q_{sy} \cdot 2$$

$$OH_{depdata, i_{data}} = 1.913 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

Figure 5-21. SY-Farm Carbon Dioxide Data.



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5.9 TANK AW-101

$$Q_{aw1} := 229 \text{ cfm}$$

$$T_{sup_aw1} := 80 \text{ F}$$

$$\Delta T_{aw1} := 4.7 \text{ F}$$

$$V_{sup_aw1} := 736 \text{ kgal}$$

$$OH_{data} := 5.6 \text{ M}$$

$$\Delta T_{liq} := 0 \text{ F}$$

$$CO3_{aw1} := \frac{5000 \frac{\text{mole}}{\text{yr}} \cdot 10 \text{ yr}}{V_{sup_aw1}}$$

$$CO3_{aw1} = 0.018 \text{ M}$$

$$L_{crust_aw1} := 30 \text{ in}$$

$$E := .02$$



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$$Q := Q_{aw1}$$

$$T_{sup} := T_{sup_aw1}$$

$$CO3_{bulk} := CO3_{aw1}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .000464 \cdot OH_{data}$$

$$CO3_{i_guess} := 672 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 12.06 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, L_{crust_aw1}, E \cdot A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, L_{crust_aw1}, E \cdot A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, L_{crust_aw1}, E \cdot A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 325 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{aw1}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 328.805 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.008 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 9.499 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 2.866 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 4.75 \times 10^3 \frac{\text{mole}}{\text{yr}}$$



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$$F_{aw1} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{aw1} = 0.087$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{aw1})$$

$$C_{co2} = 365.339 \text{ ppm}$$

$$OH_{dep_{aw1}} := OH_{dep}$$

$$i_{data} := 34$$

$$OH_{dep_{calc}}_{i_{data}} := OH_{dep}$$

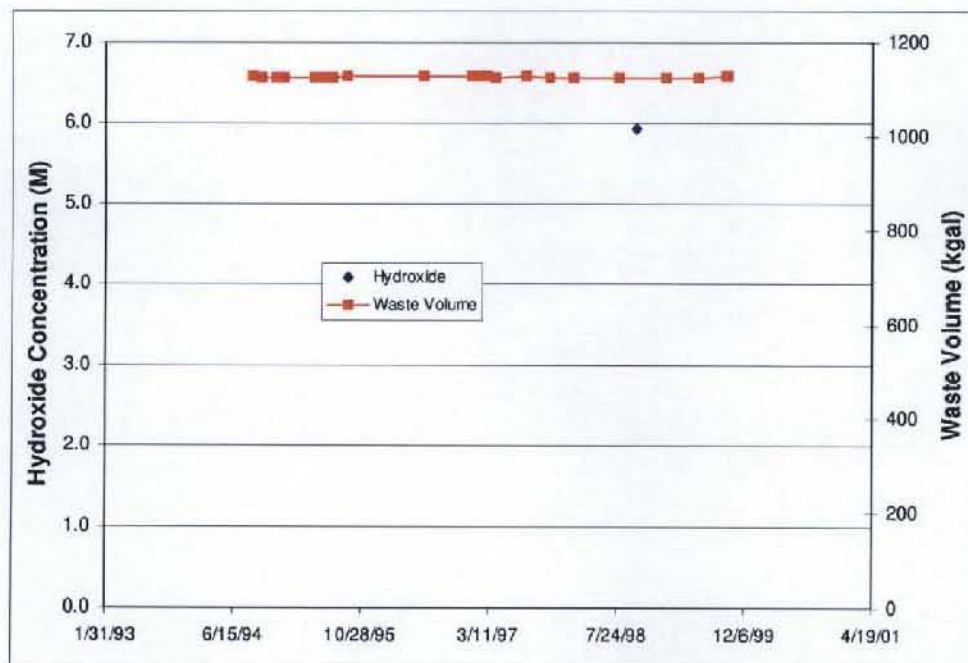
$$CO2_{data} := 379 \text{ ppm}$$

$$OH_{dep_{data}}_{i_{data}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs}_{i_{data}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

Figure 5-22. AW-101 Waste Level and Hydroxide Sample Data.





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$$Q := .33Q_{awl}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .000449 \cdot OH_{data}$$

$$CO3_{i_guess} := 550 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 9.871 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, L_{crust_awl}, E \cdot A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, L_{crust_awl}, E \cdot A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, L_{crust_awl}, E \cdot A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 284 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{awl}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 278.586 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.009 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 8.181 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 2.345 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 4.091 \times 10^3 \frac{\text{mole}}{\text{yr}}$$



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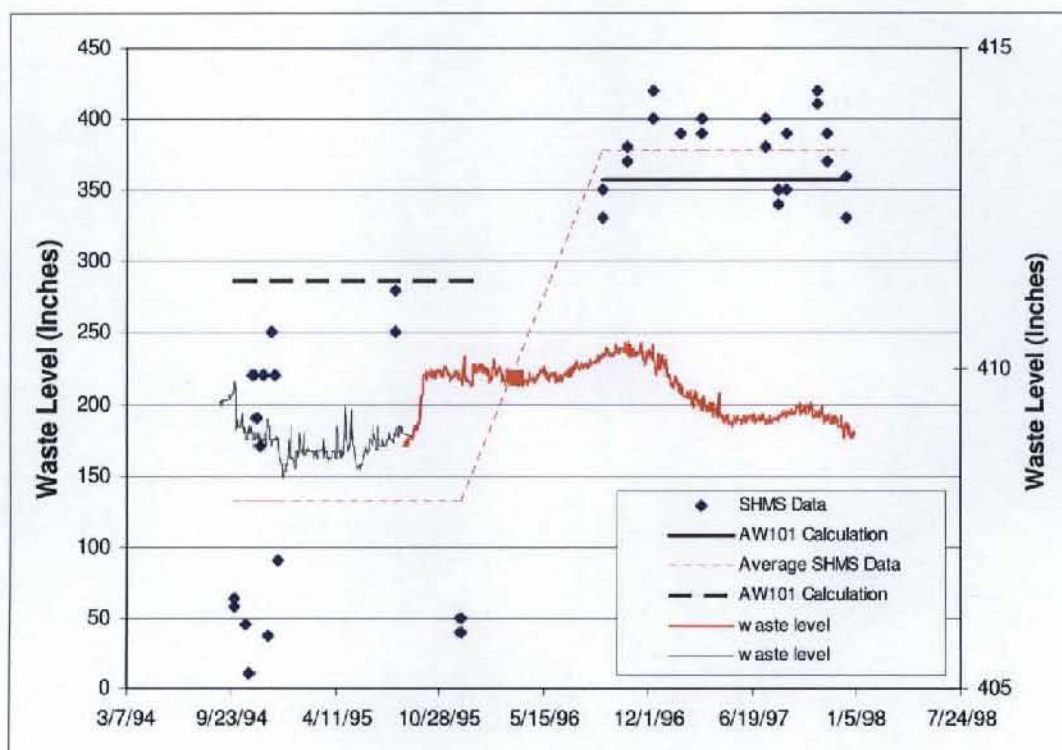
$$F_{aw1} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{aw1} = 0.226$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{aw1})$$

$$C_{co2} = 309.54 \text{ ppm}$$

Figure 5-23. AW-101 Carbon Dioxide Data.





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5.10 AW-Farm Ventilation

Figure 5-24. AW-Farm Carbon Dioxide Data.

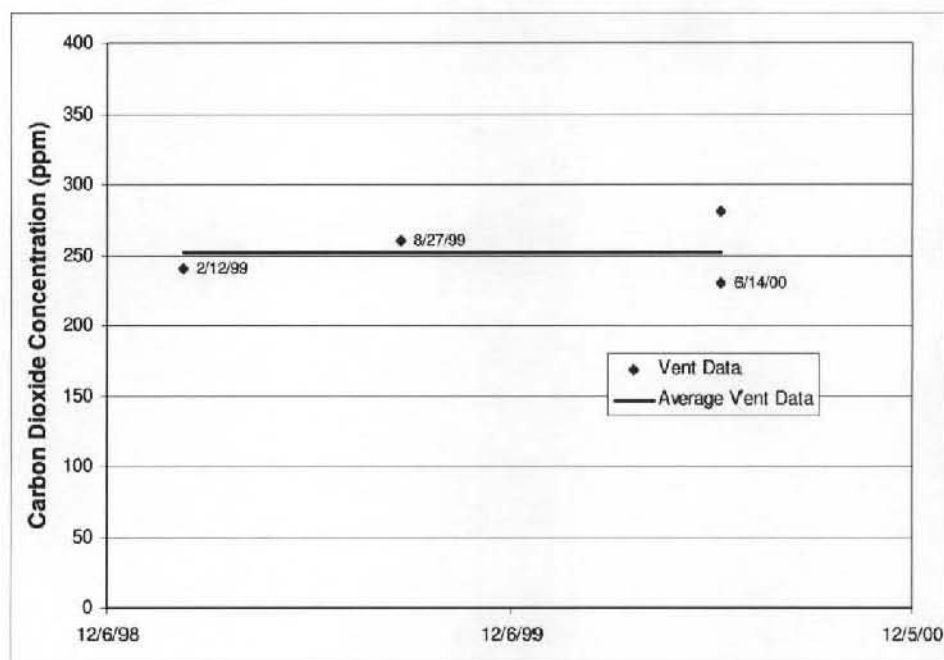


Table 5-1. AW-Farm Ventilation Flow Rates.

	FCD Flow (cfm)	Total Flow (cfm)
AW101	125	229
AW102	70	174
AW103	35	139
AW104	35	139
AW105	35	139
AW106	35	139
Total FCD Flow (cfm)	335	
Total Farm Flow (cfm)	960	



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5.10.1 AW-Farm Tank AW-101

There temperature profiles for Periods 1 and two are shown below. The analyses for Section 5.9 will be used.

$$Q_{aw1} := 229 \text{ cfm}$$

$$OH_{dep_{aw1}} = 9.499 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$F_{aw1} := \frac{\frac{OH_{dep_{aw1}}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q_{aw1}}$$

$$F_{aw1} = 0.087$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{aw1})$$

$$C_{co2} = 365.339 \text{ ppm}$$

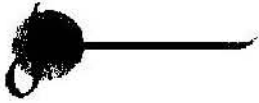
The depletion rate based upon the Hobbs model is

$$OH_{hobbs_{aw1}} := OH_{dephobbs_{data}}$$

Figure 5-25. AW-101 Vapor Space and Supernatant Temperatures.



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5.10.2 AW-FARM TANK AW-102

$$Q_{aw2} := 174 \text{ cfm}$$

$$T_{sup_aw2} := 70 \text{ F}$$

$$\Delta T_{aw2} := 1. \text{ F}$$

$$V_{sup_aw2} := 600 \text{ kgal}$$

$$OH_{data} := .57 \text{ M}$$

$$CO3_{aw2} := \frac{30000 \frac{\text{mole}}{\text{yr}} \cdot 10 \text{ yr}}{V_{sup_aw2}}$$

$$CO3_{aw2} = 0.132 \text{ M}$$



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$$Q := Q_{aw2}$$

$$T_{sup} := T_{sup_aw2}$$

$$CO3_{bulk} := CO3_{aw2}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .85 \cdot OH_{data}$$

$$CO3_{i_guess} := 3.5 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.462 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 61 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{aw2}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 62.995 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 5.777 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 6.872 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 2.947 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 3.436 \times 10^4 \frac{\text{mole}}{\text{yr}}$$



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$$F_{aw2} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{aw2} = 0.825$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{aw2})$$

$$C_{co2} = 69.994 \text{ ppm}$$

$$OH_{depaw2} := OH_{dep}$$

$$F_{aw2} := \frac{\frac{OH_{depaw2}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q_{aw2}}$$

$$F_{aw2} = 0.825$$

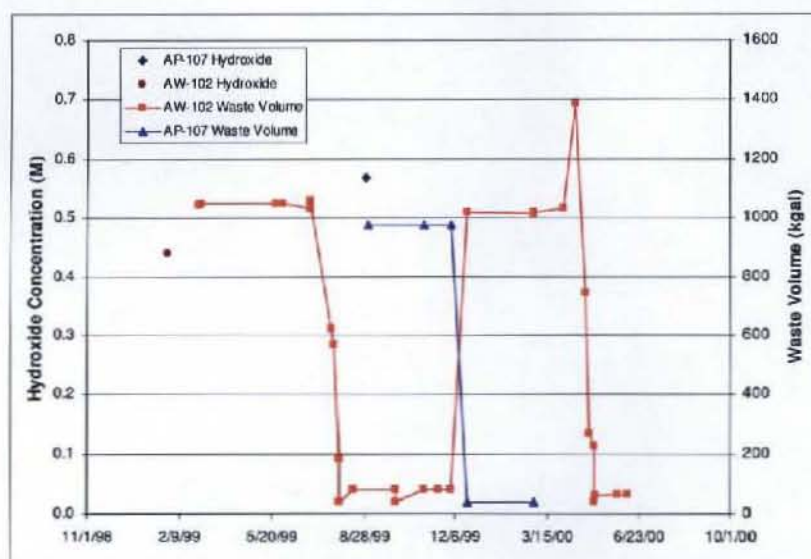
$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{aw2})$$

$$C_{co2} = 69.994 \text{ ppm}$$

The depletion rate based upon the Hobbs model is

$$OH_{hobbsaw2} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

Figure 5-26. AW-102 Waste Volume and Hydroxide Data.

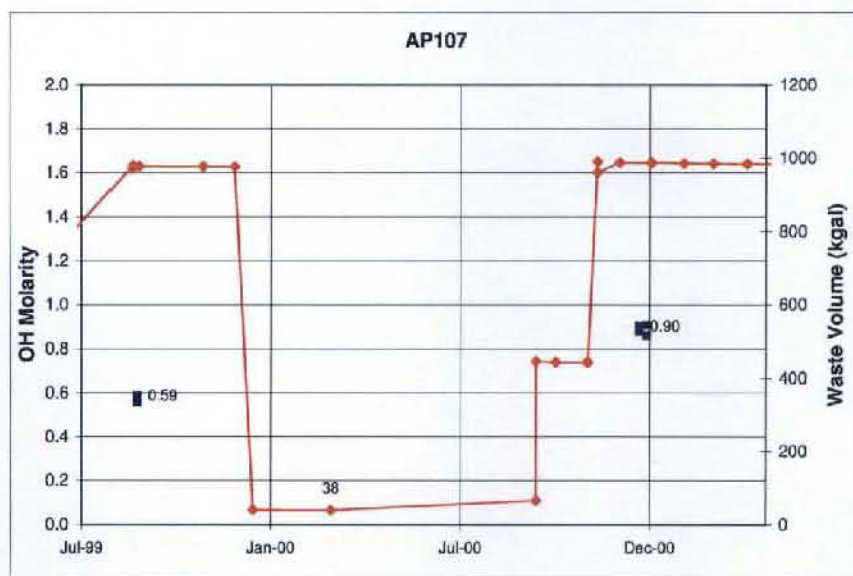
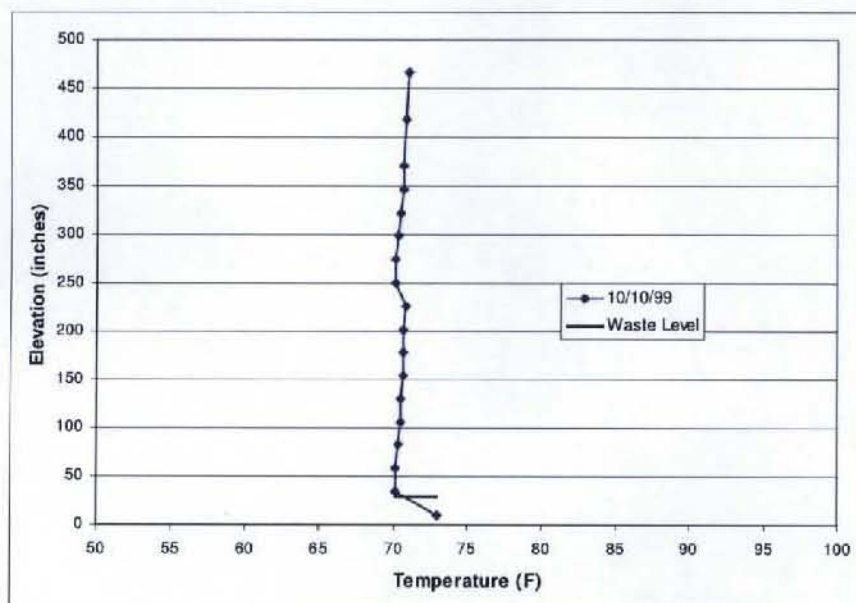




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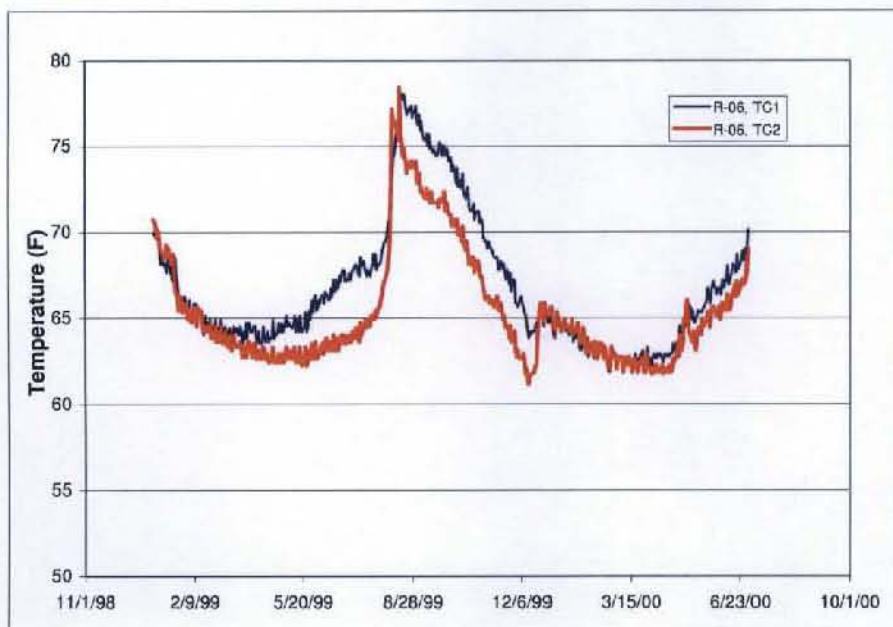
Figure 5-27. AP-107 Waste Volume and Hydroxide Data.**Figure 5-28. AW-102 10/10/99 Waste Temperature Profile.**



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Figure 5-29. AW-102 Vapor Space and Supernatant Temperatures.

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5.10.3 AW-FARM TANK AW-103

$$Q_{aw3} := 139 \text{ cfm}$$

$$T_{sup_aw3} := 70 \text{ F}$$

The vapor space temperature exceeded the supernatant temperature for two out of three data points.

$$\Delta T_{aw3} := -.1 \text{ F}$$

$$V_{solidsaw3} := 313 \text{ kgal}$$

$$V_{sup_aw3} := 510 \text{ kgal} - V_{solidsaw3}$$

$$OH_{data} := .57 \text{ M}$$

$$CO3_{aw3} := \frac{30000 \frac{\text{mole}}{\text{yr}} \cdot 10 \text{ yr}}{V_{sup_aw3}}$$

$$CO3_{aw3} = 0.402 \text{ M}$$



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$$Q := Q_{aw3}$$

$$T_{sup} := T_{sup_aw3}$$

$$CO3_{bulk} := CO3_{aw3}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .93 \cdot OH_{data}$$

$$CO3_{i_guess} := 1.4 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.563 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 217 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{aw3}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 215.207 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 2.696 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 2.676 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.436 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.338 \times 10^4 \frac{\text{mole}}{\text{yr}}$$



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$$F_{aw3} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{aw3} = 0.402$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{aw3})$$

$$C_{co2} = 239.119 \text{ ppm}$$

$$OH_{dep_{aw3}} := OH_{dep}$$

$$F_{aw3} := \frac{\frac{OH_{dep_{aw3}}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q_{aw3}}$$

$$F_{aw3} = 0.402$$

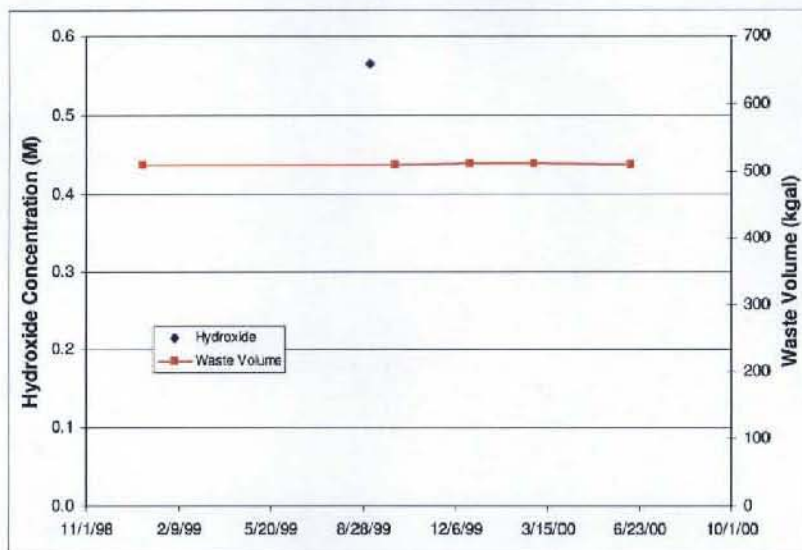
$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{aw3})$$

$$C_{co2} = 239.119 \text{ ppm}$$

The depletion rate based upon the Hobbs model is

$$OH_{hobbs_{aw3}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

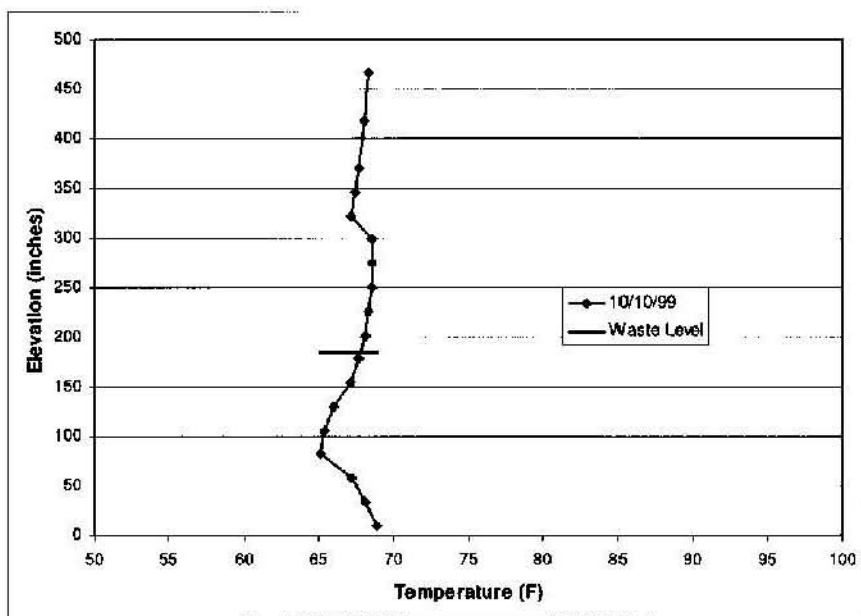
Figure 5-30. AW-103 Waste Volume and Hydroxide Data.



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Figure 5-31. AW-103 10/10/99 Waste Temperature Profile.

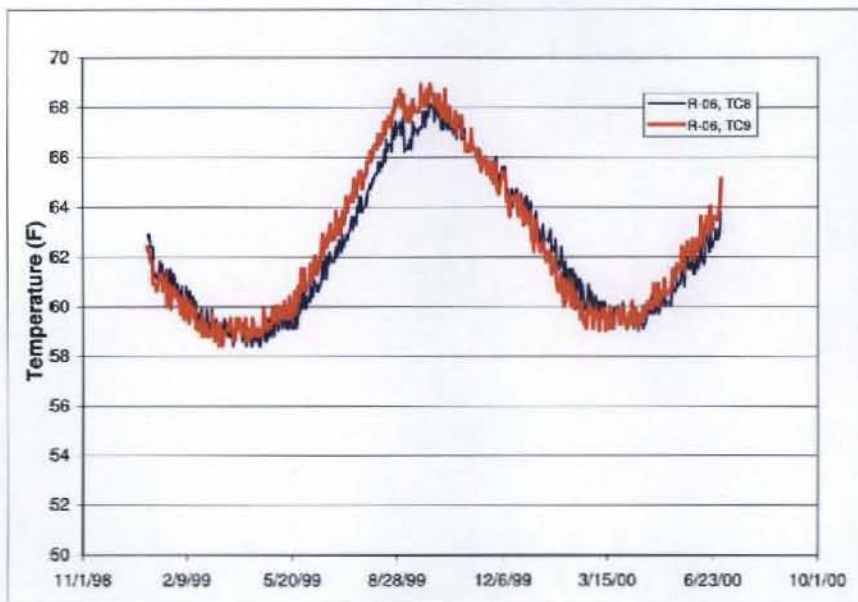


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Figure 5-32. AW-103 10/10/99 Vapor Space and Supernatant Temperatures.



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5.10.4 AW-FARM TANK AW-104

$$Q_{aw4} := 139 \text{ cfm}$$

$$T_{sup_aw4} := 70 \text{ F}$$

$$\Delta T_{aw4} := 1.5 \text{ F}$$

$$V_{solid_{sup_{aw4}}} := 157 \text{ kgal} + 66 \text{ kgal}$$

$$V_{sup_aw4} := 1118 \text{ kgal} - V_{solid_{sup_{aw4}}}$$

$$OH_{data} := .07 \text{ M}$$

$$CO3_{aw4} := \frac{30000 \frac{\text{mole}}{\text{yr}} \cdot 10 \text{ yr}}{V_{sup_aw4}}$$

$$CO3_{aw4} = 0.089 \text{ M}$$



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$$Q := Q_{aw4}$$

$$T_{sup} := T_{sup_aw4}$$

$$CO3_{bulk} := CO3_{aw4}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .0114 \cdot OH_{data}$$

$$CO3_{i_guess} := 3.6 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.319 M$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 123.5 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{aw4}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 123.657 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 4.676 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 4.368 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 2.054 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 2.184 \times 10^4 \frac{\text{mole}}{\text{yr}}$$



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$$F_{aw4} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{aw4} = 0.657$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{aw4})$$

$$C_{co2} = 137.397 \text{ ppm}$$

$$OH_{dep_{aw4}} := OH_{dep}$$

$$F_{aw4} := \frac{\frac{OH_{dep_{aw4}}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q_{aw4}}$$

$$F_{aw4} = 0.657$$

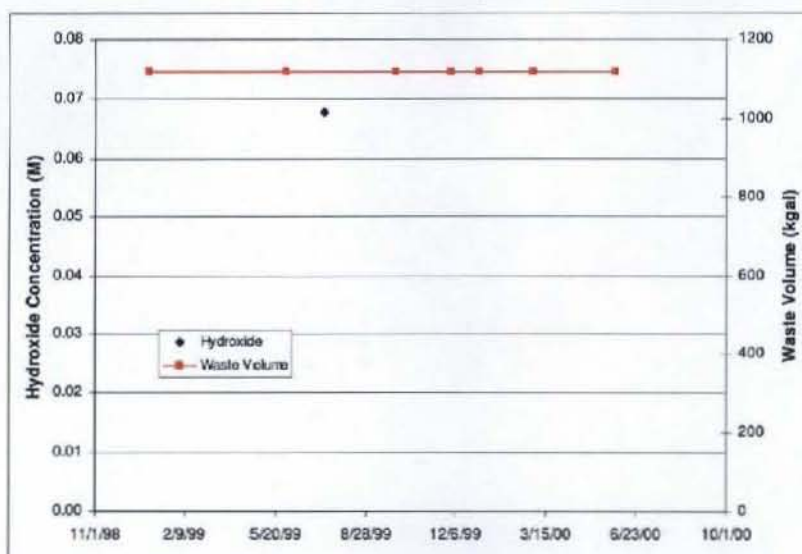
$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{aw4})$$

$$C_{co2} = 137.397 \text{ ppm}$$

The depletion rate based upon the Hobbs model is

$$OH_{hobbs_{aw4}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

Figure 5-33. AW-104 Waste Volume and Hydroxide Data.

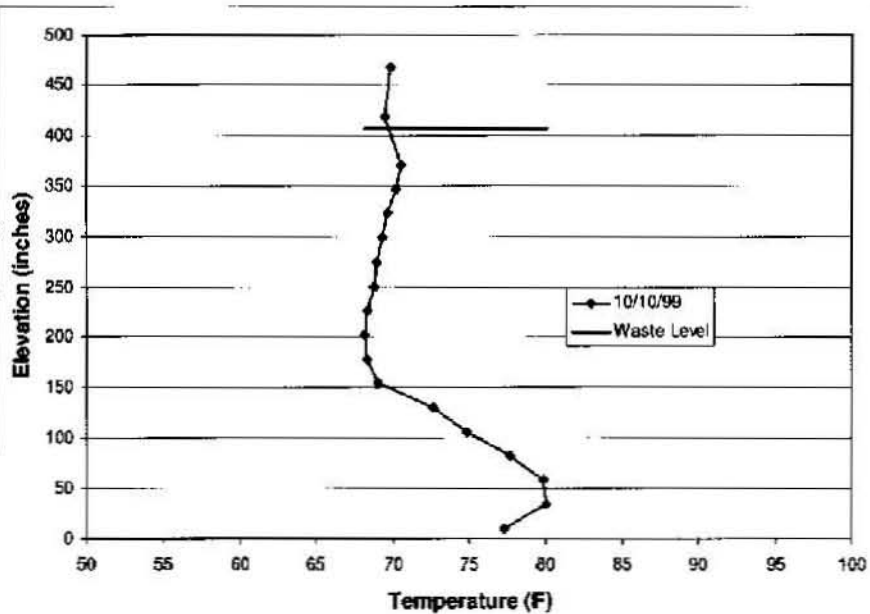


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Figure 5-34. AW-104 10/10/99 Waste Temperature Profile.

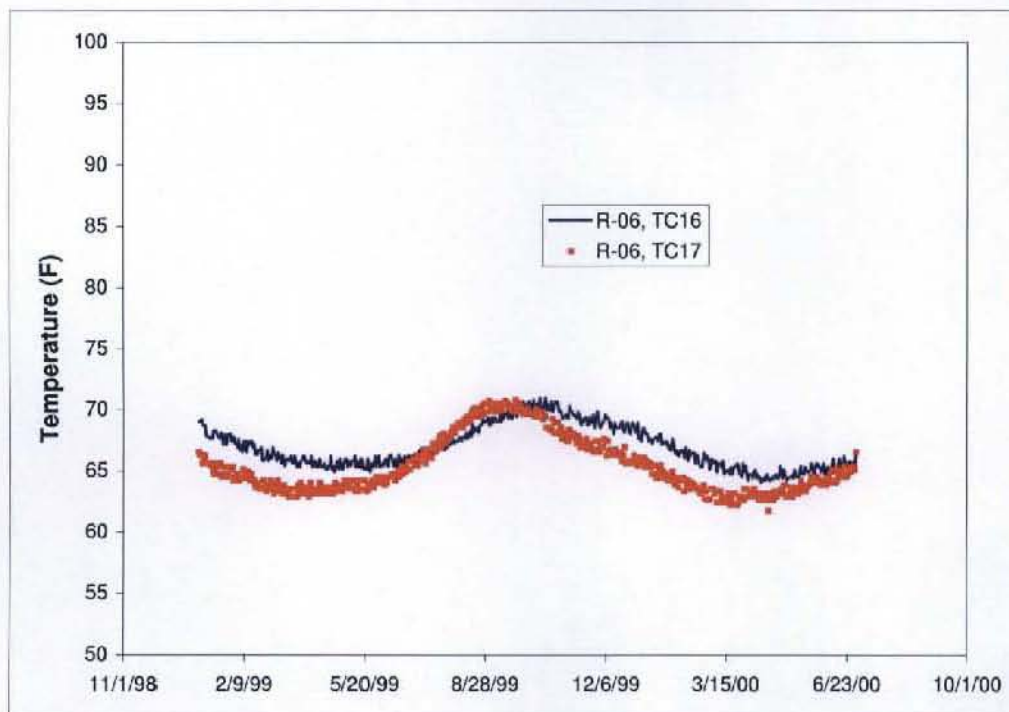




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Figure 5-35. AW-104 Vapor Space and Supernatant Temperatures.

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5.10.5 AW-FARM TANK AW-105

$$Q_{aw5} := 139 \text{ cfm}$$

$$T_{sup_aw5} := 70 \text{ F}$$

$$\Delta T_{aw5} := -.1 \text{ F}$$

$$V_{solidsaw5} := 263 \text{ kgal}$$

$$V_{sup_aw5} := 425 \text{ kgal} - V_{solidsaw5}$$

$$OH_{data} := .25 \text{ M}$$

$$CO3_{aw5} := \frac{10000 \frac{\text{mole}}{\text{yr}} \cdot 10 \text{ yr}}{V_{sup_aw5}}$$

$$CO3_{aw5} = 0.163 \text{ M}$$



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$$Q := Q_{aw5}$$

$$T_{sup} := T_{sup_aw5}$$

$$CO3_{bulk} := CO3_{aw5}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .92 \cdot OH_{data}$$

$$CO3_{i_guess} := 2 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.326 M$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 217 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{aw5}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 215.208 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.351 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 2.676 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.455 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.338 \times 10^4 \frac{\text{mole}}{\text{yr}}$$



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$$F_{aw5} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{aw5} = 0.402$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{aw5})$$

$$C_{co2} = 239.12 \text{ ppm}$$

$$OH_{dep_{aw5}} := OH_{dep}$$

$$F_{aw5} := \frac{\frac{OH_{dep_{aw5}}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q_{aw5}}$$

$$F_{aw5} = 0.402$$

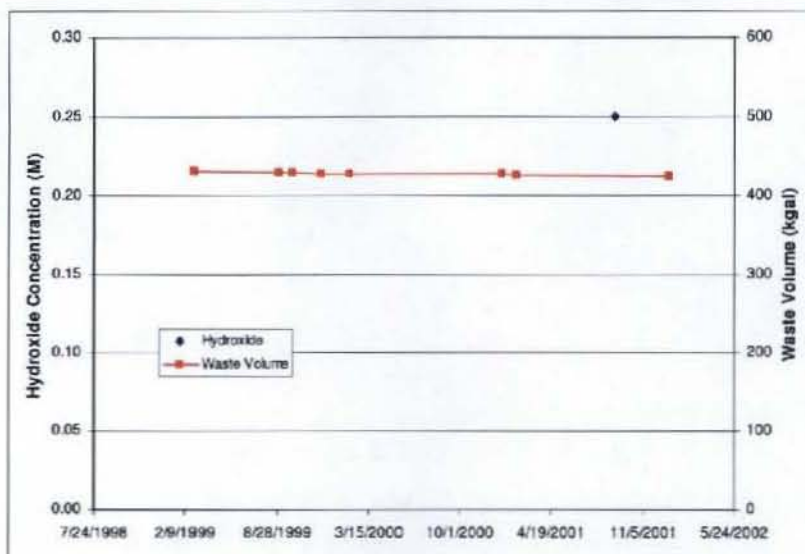
$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{aw5})$$

$$C_{co2} = 239.12 \text{ ppm}$$

The depletion rate based upon the Hobbs model is

$$OH_{hobbs_{aw5}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

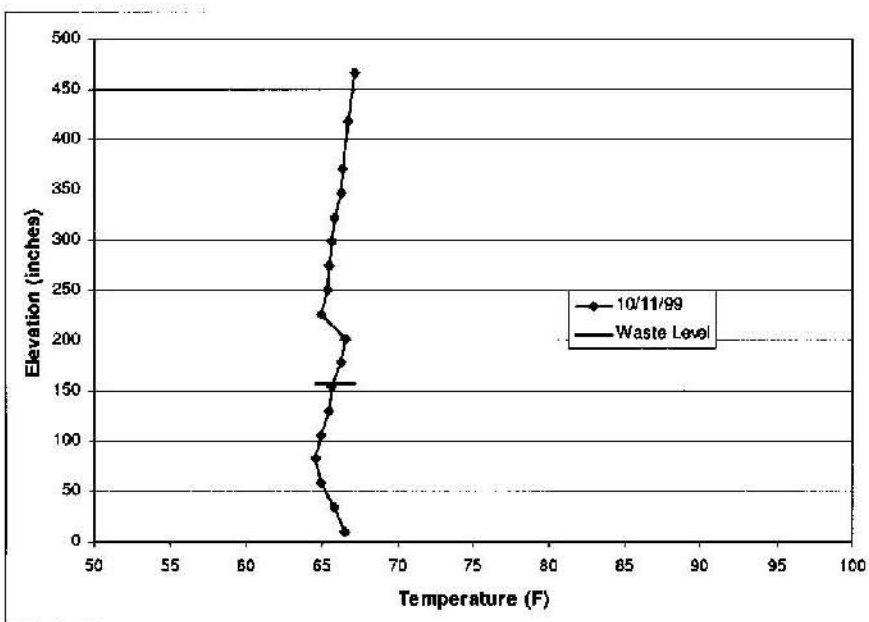
Figure 5-36. AW-105 Waste Volume and Hydroxide Data.



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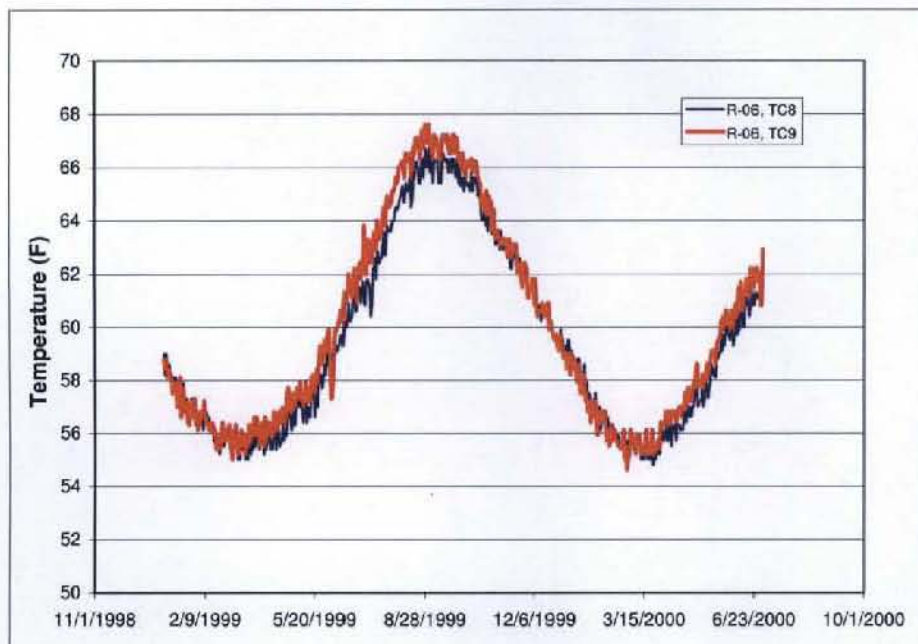
Figure 5-37. AW-105 10/11/99 Waste Temperature Profile.



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Figure 5-38. AW-105 Vapor Space and Supernatant Temperatures.

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5.10.6 AW-FARM TANK AW-106

$$Q_{aw6} := 139 \text{ cfm}$$

$$T_{sup_aw6} := 85 \text{ F}$$

$$\Delta T_{aw6} := .1 \text{ F}$$

$$V_{solidsaw6} := 283 \text{ kgal}$$

$$V_{sup_aw6} := 740 \text{ kgal} - V_{solidsaw6}$$

See AW102 for OH concentration for last transfer.

$$OH_{data} := .58 \text{ M}$$

$$CO3_{aw6} := \frac{30000 \frac{\text{mole}}{\text{yr}} \cdot 10 \text{ yr}}{V_{sup_aw6}}$$

$$CO3_{aw6} = 0.173 \text{ M}$$



$$Q := Q_{aw6}$$

$$T_{sup} := T_{sup_aw6}$$

$$CO3_{bulk} := CO3_{aw6}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .88 \cdot OH_{data}$$

$$CO3_{i_guess} := 2.5 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.434 M$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 97 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{aw6}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 97.751 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 4.702 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 4.847 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 2.321 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 2.424 \times 10^4 \frac{\text{mole}}{\text{yr}}$$



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$$F_{aw6} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{aw6} = 0.728$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{aw6})$$

$$C_{co2} = 108.612 \text{ ppm}$$

$$OH_{dep_{aw6}} := OH_{dep}$$

$$F_{aw6} := \frac{\frac{OH_{dep_{aw6}}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q_{aw6}}$$

$$F_{aw6} = 0.728$$

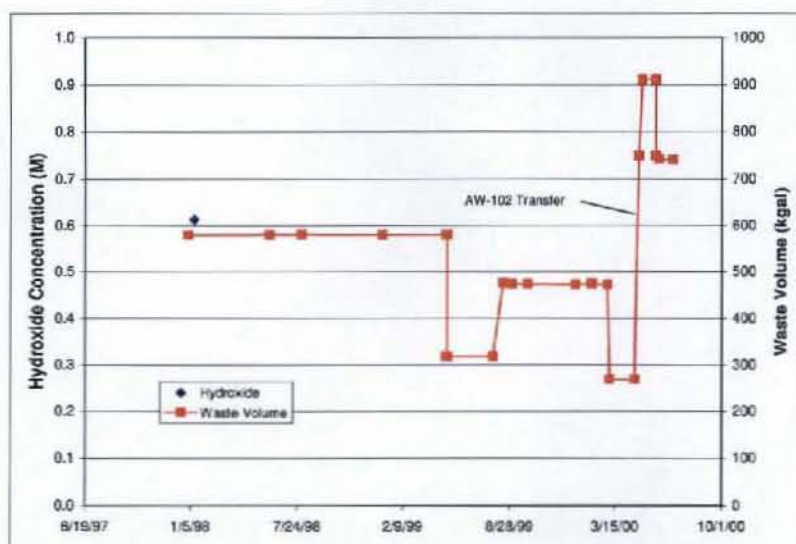
$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{aw6})$$

$$C_{co2} = 108.612 \text{ ppm}$$

The depletion rate based upon the Hobbs model is

$$OH_{hobbs_{aw6}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

Figure 5-39. AW-106 Waste Volume and Hydroxide Data.

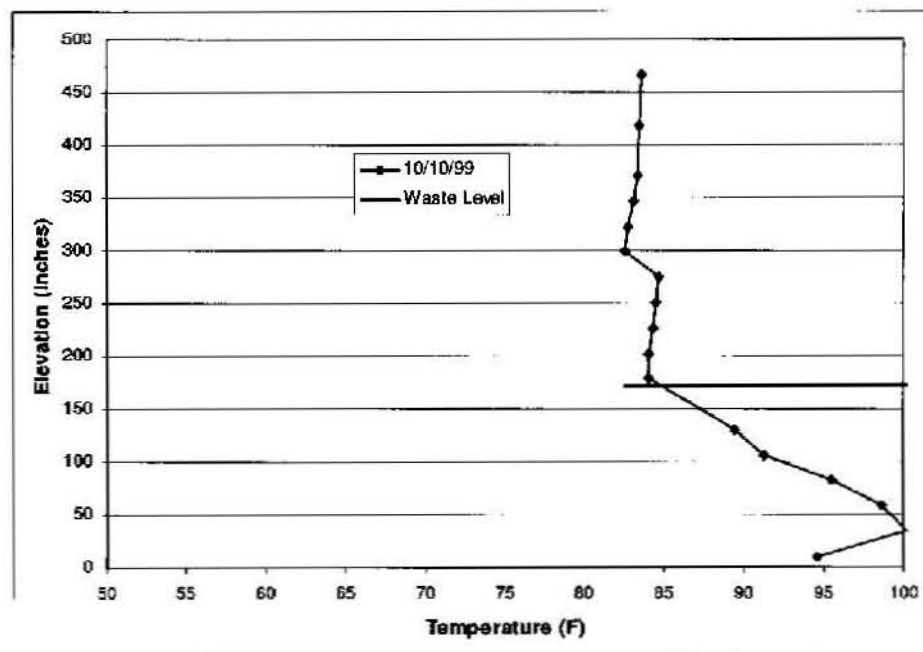


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Figure 5-40. AW-106 10/10/99 Waste Temperature Profile.

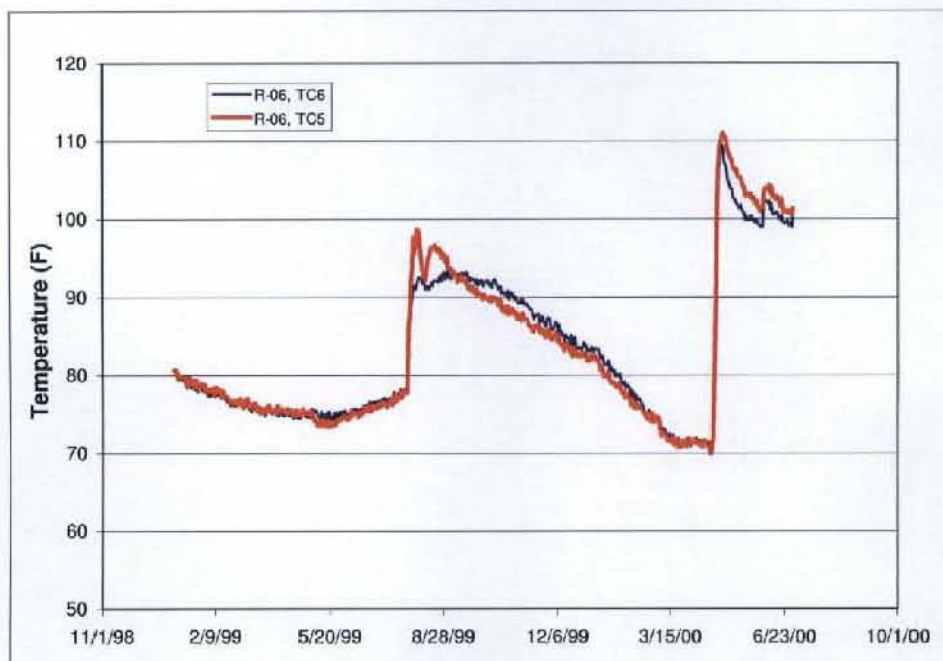




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Figure 5-41. AW-106 Vapor Space and Supernatant Temperatures.

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5.10.7 AW_Farm Results

$$Q_{aw} := Q_{aw1} + Q_{aw2} + Q_{aw3} + Q_{aw4} + Q_{aw5} + Q_{aw6}$$

$$i_{data} := 35$$

$$OH_{depcalc, i_{data}} := OH_{dep_{aw1}} + OH_{dep_{aw2}} + OH_{dep_{aw3}} + OH_{dep_{aw4}} + OH_{dep_{aw5}} + OH_{dep_{aw6}}$$

$$OH_{depcalc, i_{data}} = 2.239 \times 10^5 \frac{\text{mol}}{\text{yr}}$$

$$OH_{dephobbs, i_{data}} := OH_{hobbs_{aw1}} + OH_{hobbs_{aw2}} + OH_{hobbs_{aw3}} + OH_{hobbs_{aw4}} + OH_{hobbs_{aw5}} + OH_{hobbs_{aw6}}$$

$$CO2_{data} := 252 \text{ ppm}$$

$$OH_{depdata, i_{data}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{aw} \cdot 2$$

$$OH_{depdata, i_{data}} = 1.699 \times 10^5 \frac{\text{mol}}{\text{yr}}$$

$$F_{aw} := \frac{OH_{depcalc, i_{data}}}{x_{co2_amb} \cdot C_{air} \cdot Q_{aw}}$$

$$F_{aw} = 0.488$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{aw})$$

$$C_{co2} = 204.914 \text{ ppm}$$



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5.10 TANK AN-101

5.10.1 Period 1

$$Q_{an1} := 92 \text{ cfm}$$

$$T_{sup_an1} := 65 \text{ F}$$

$$\Delta T_{an1} := .043 \text{ F}$$

$$V_{saltcake} := 0 \text{ kgal}$$

$$z_{saltcake} := \frac{V_{saltcake}}{A_{tank}}$$

$$z_{saltcake} = 0 \text{ in}$$

$$V_{sup_an1} := (57 \text{ in} \cdot A_{tank}) - V_{saltcake}$$

$$OH_{data} := .4 \text{ M}$$

$$\Delta T_{liq} := 0 \text{ F}$$

$$CO3_{an1} := \frac{20000 \frac{\text{mole}}{\text{yr}} \cdot 15 \text{ yr}}{V_{sup_an1}}$$

$$CO3_{an1} = 0.505 \text{ M}$$

$$D_{liq} = 4 \text{ in}$$

Table 5-2. AN-Farm Ventilation Flow Rates.

ECN Number	ECN Date	Tank FCS Flow (cfm)							Total FCS Flow (cfm)	Average Total Flow (cfm)
		AN101	AN102	AN103	AN104	AN105	AN106	AN107		
710248	5/6/1999	60	60	100	100	100	60	60	540	764
661166	8/31/2000	60	60	60	60	60	60	60	420	764
666412	5/7/2001	60	60	60	60	60	60	90	450	764
666600	6/27/2001	60	90	60	60	60	60	60	450	764
ECN Number	ECN Date	Total Tank Flow (cfm)								
		AN101	AN102	AN103	AN104	AN105	AN106	AN107		
710248	5/6/1999	92	92	132	132	132	92	92		
661166	8/31/2000	109	109	109	109	109	109	109		
666412	5/7/2001	105	105	105	105	105	105	135		
666600	6/27/2001	105	135	105	105	105	105	105		



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$$Q := Q_{an1}$$

$$T_{sup} := T_{sup_an1}$$

$$CO3_{bulk} := CO3_{an1}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .88 \cdot OH_{data}$$

$$CO3_{i_guess} := 1.36 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.687 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 84 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{an1}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 84.264 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.243 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 3.373 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.622 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.687 \times 10^4 \frac{\text{mole}}{\text{yr}}$$



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$$\frac{OH_{dep}}{2} = 1.687 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$F_{an1} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{an1} = 0.766$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{an1})$$

$$C_{co2} = 93.627 \text{ ppm}$$

$$i_{data} := 36$$

$$OH_{depcalc, i_{data}} := OH_{dep}$$

$$CO2_{data} := 73 \text{ ppm}$$

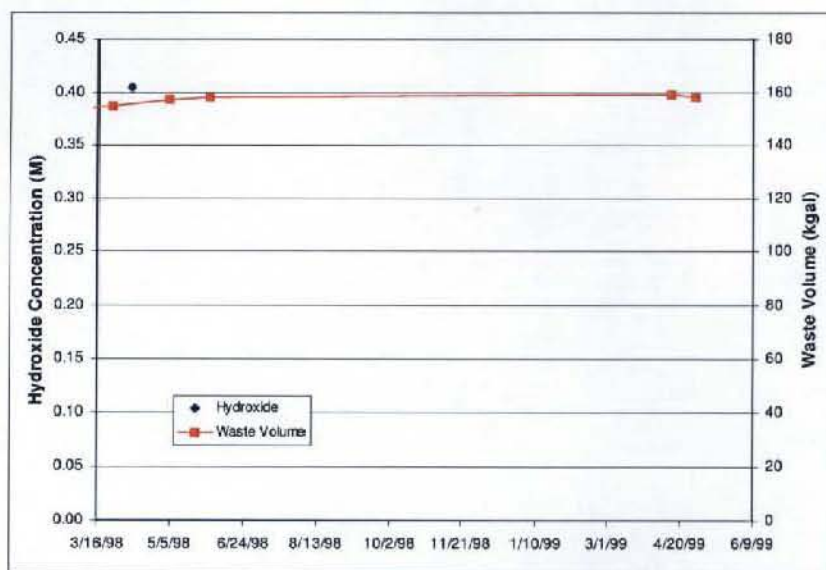
$$OH_{depdata, i_{data}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs, i_{data}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

$$OH_{dataan1, i} := OH_{data}$$

Figure 5-42. AN-101 Waste Volume and Hydroxide Data.

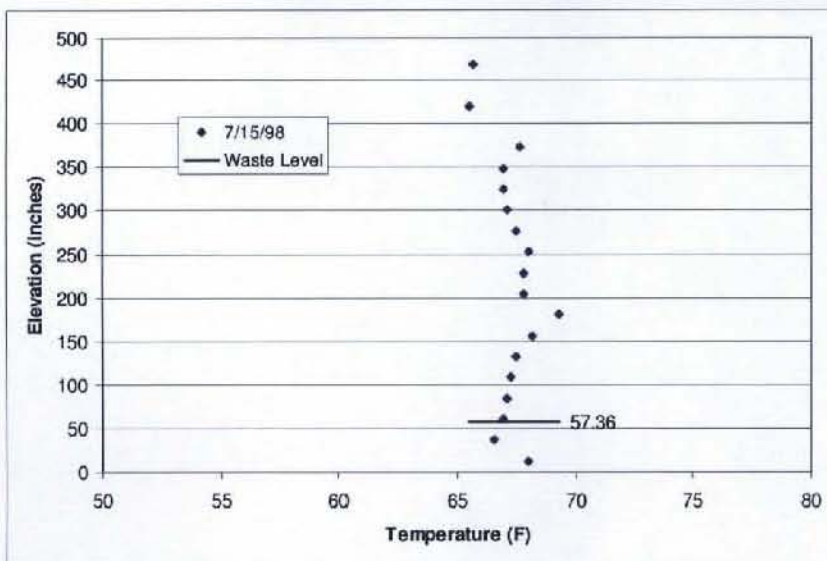
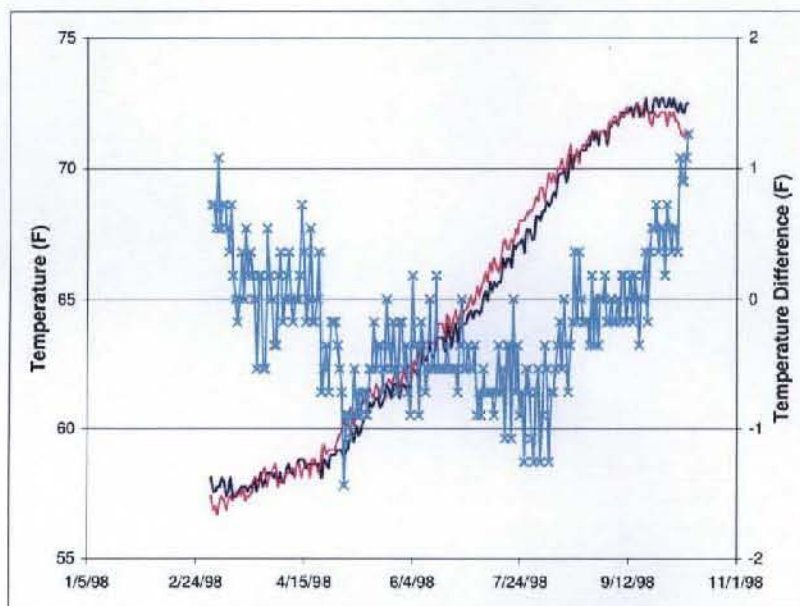




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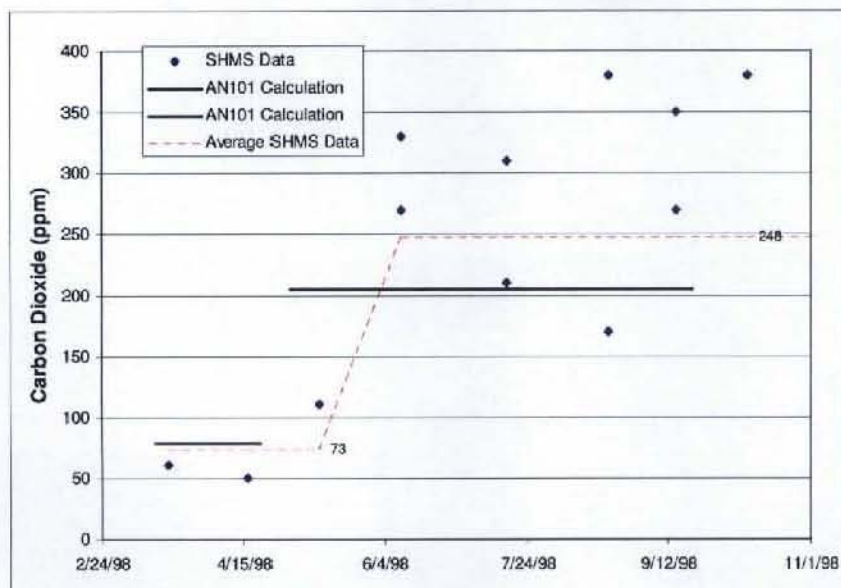
Figure 5-43. AN-101 7/15/98 Waste Temperature Profile.**Figure 5-44. AN-101 Vapor Space and Supernatant Temperatures.**



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Figure 5-45. AN-101 Carbon Dioxide Data.

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5.10.2 Period 2

$$\Delta T_{\text{ad1}} := -.01F$$



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$$Q := Q_{an1}$$

$$T_{sup} := T_{sup_an1}$$

$$CO3_{bulk} := CO3_{an1}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .94 \cdot OH_{data}$$

$$CO3_{i_guess} := 1.19 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.601 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 230 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{an1}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 227.904 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.622 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.616 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 8.56 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 8.08 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

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$$\frac{OH_{dep}}{2} = 8.08 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$F_{anl} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{anl} = 0.367$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{anl})$$

$$C_{co2} = 253.227 \text{ ppm}$$

$$i_{data} := 37$$

$$OH_{depcalc, i_{data}} := OH_{dep}$$

$$CO2_{data} := 281 \text{ ppm}$$

$$OH_{depdata, i_{data}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs, i_{data}} := 2 x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

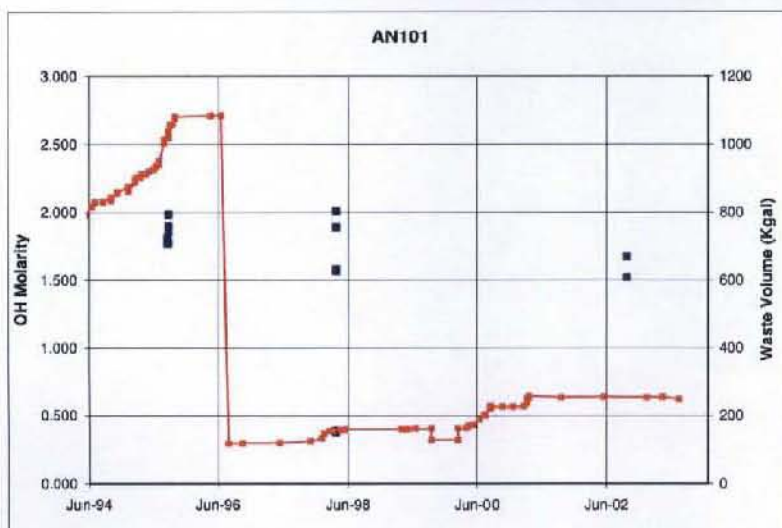
$$OH_{dataanl_2} := OH_{data}$$



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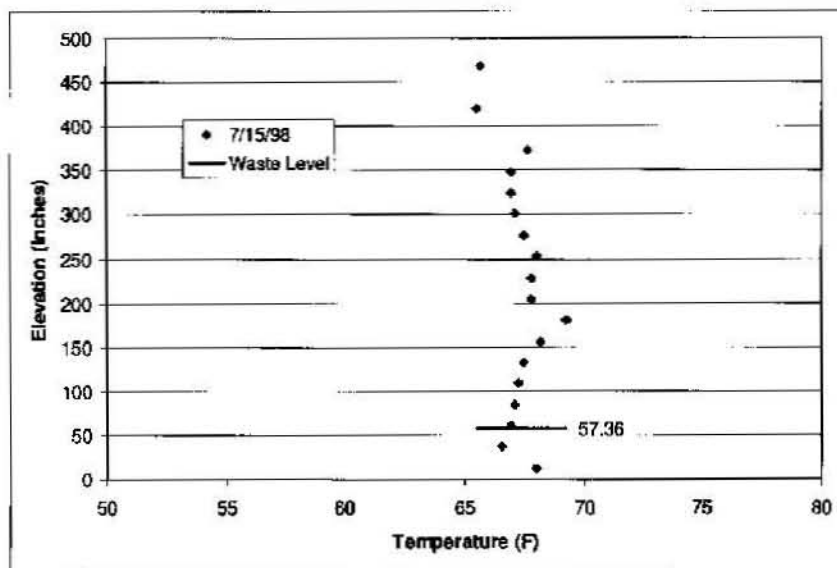
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Figure 5-46. AN-101 Waste Volume and Hydroxide Data.

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Figure 5-47. AN-101 7/15/98 Waste Temperature Profile.

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5.11 TANK AN-103

$$Q_{an3} := 132 \text{ cfm}$$

$$T_{sup_an3} := 100\text{F}$$

$$\Delta T_{an3} := \Delta T_{an3}$$

$$V_{saltcake} := 459 \text{ kgal}$$

$$V_{sup_an3} := (349 \text{ in} \cdot A_{tank}) - V_{saltcake}$$

$$OH_{data} := 5.0 \text{ M}$$

$$OH_{data_an3} := OH_{data}$$

$$\Delta T_{liq} := 0\text{F}$$

$$CO3_{an3} := \frac{9000 \frac{\text{mole}}{\text{yr}} \cdot 8 \text{ yr}}{V_{sup_an3}}$$

$$CO3_{an3} = 0.038 \text{ M}$$

$$I_{crust_an3} := 25 \text{ in} + \frac{25 \text{ in}}{2}$$

$$L_{crust_an3} = 37.5 \text{ in}$$



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$$Q := Q_{an3}$$

$$T_{sup} := T_{sup_an3}$$

$$CO3_{bulk} := CO3_{an3}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .000403 \cdot OH_{data}$$

$$CO3_{i_guess} := 195 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 7.386 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, L_{crust_an3}, E \cdot A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, L_{crust_an3}, E \cdot A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, L_{crust_an3}, E \cdot A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 329.5 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{an3}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 330.34 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 7.204 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 5.206 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.399 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 2.603 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

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$$\frac{OH_{dep}}{2} = 2.603 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$F_{an3} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{an3} = 0.082$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{an3})$$

$$C_{co2} = 367.045 \text{ ppm}$$

$$OH_{dep_{an3}} := OH_{dep}$$

$$i_{data} := 38$$

$$OH_{dep_{calc}_{i_{data}}} := OH_{dep}$$

$$CO2_{data} := 355 \text{ ppm}$$

$$OH_{dep_{data}_{i_{data}}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

The depletion rate based upon the Hobbs model is

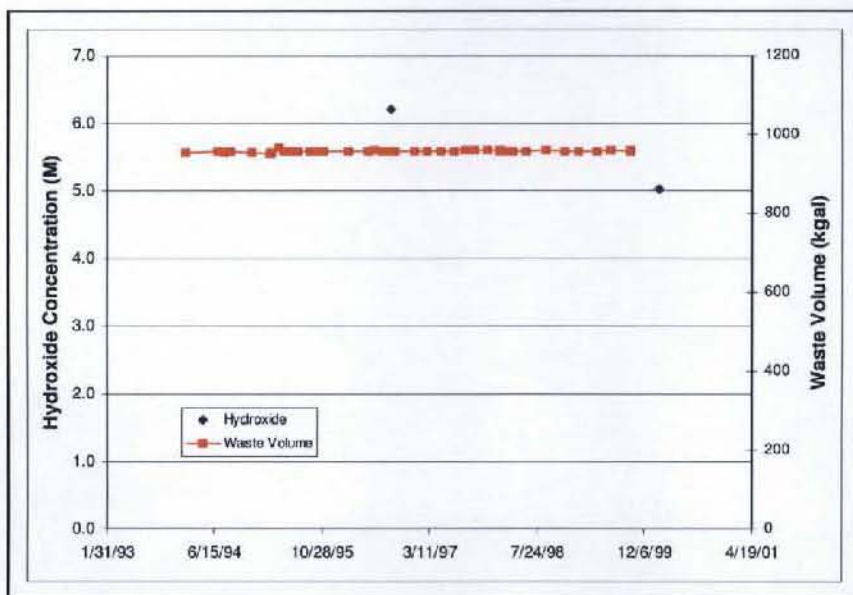
$$OH_{dephobbs_{i_{data}}} := 2 x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$



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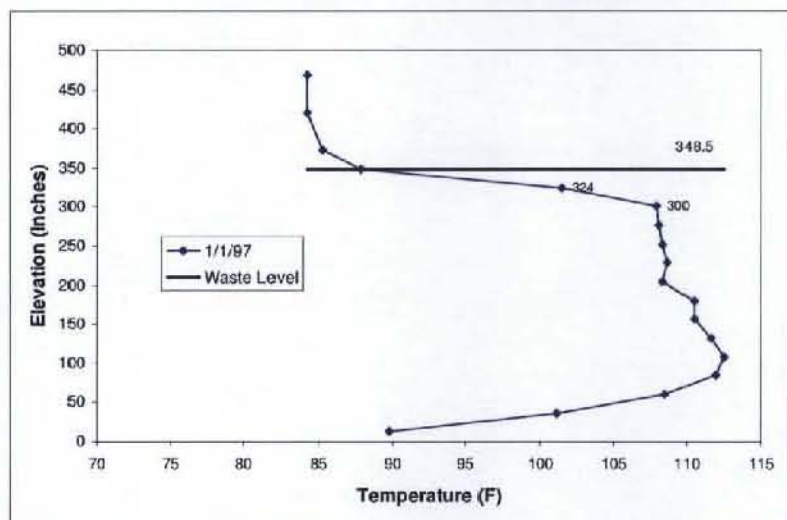
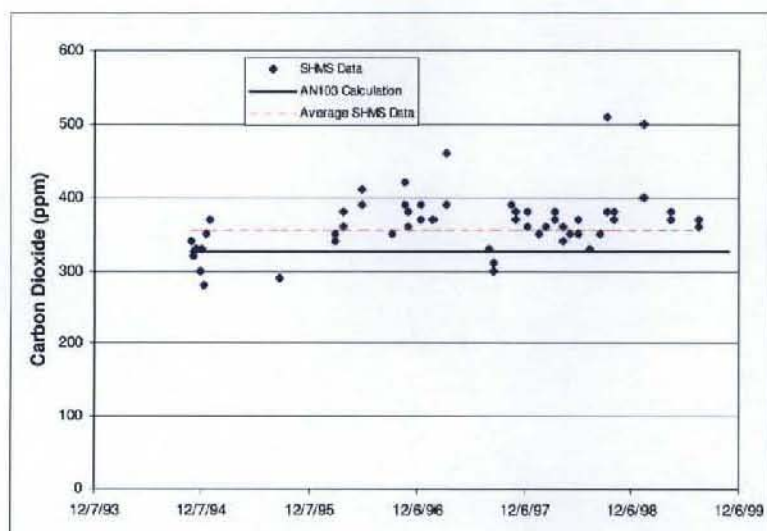
Figure 5-48. AN-103 Waste Volume and Hydroxide Data.



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Figure 5-49. AN-103 Waste Temperature Profile.**Figure 5-50. AN-103 Carbon Dioxide Data.**



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5.12 AN-104

$$x_{\text{co2_pnnl}} := 410\text{ppm}$$

$$\text{OH}_{\text{dep}} := \text{OH}_{\text{dep_an4}}$$

$$F_{\text{an4}} := \frac{\frac{\text{OH}_{\text{dep}}}{2}}{x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q_{\text{vent}_1}}$$

$$F_{\text{an4}} = 0.168$$

$$C_{\text{co2}} := x_{\text{co2_pnnl}} \cdot (1 - F_{\text{an4}})$$

$$C_{\text{co2}} = 341.314\text{ppm}$$

$$i_{\text{data}} := 39$$

$$\text{OH}_{\text{depcalc}_{i_{\text{data}}}} := \text{OH}_{\text{dep}}$$

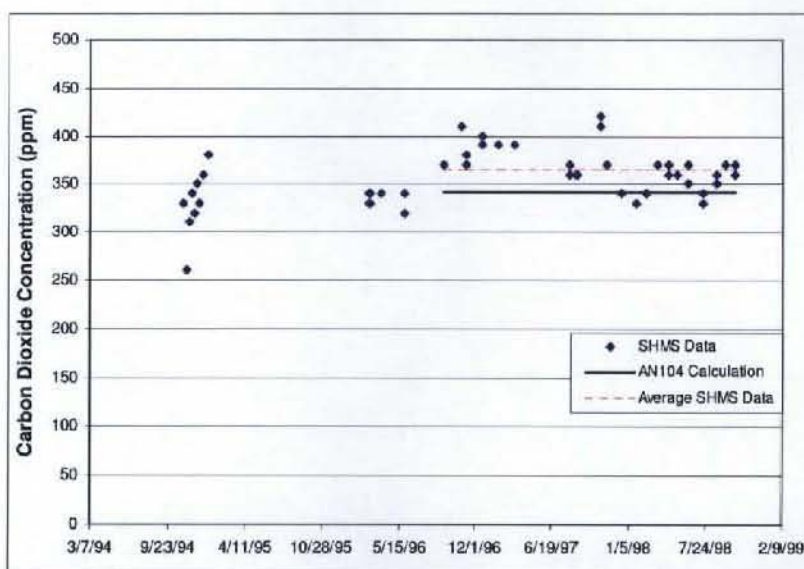
$$\text{CO2}_{\text{data}} := 365\text{ppm}$$

$$\text{OH}_{\text{depdata}_{i_{\text{data}}}} := \left(1 - \frac{\text{CO2}_{\text{data}}}{x_{\text{co2_pnnl}}} \right) \cdot x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q \cdot 2$$

The depletion rate based upon the Hobbs model is

$$\text{OH}_{\text{dephobbs}_{i_{\text{data}}}} := 2x_{\text{co2_amb}} \cdot C_{\text{air}} \cdot Q \cdot F_{\text{hobbs}}(\text{OH}_{\text{hanford_data}_1})$$

Figure 5-51. AN-104 Carbon Dioxide Data.





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5.13 AN-105

$$OH_{dep} := OH_{dep_an5}$$

$$F_{an5} := \frac{OH_{dep}}{2 \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{vent2}}$$

$$F_{an5} = 0.176$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{an5})$$

$$C_{co2} = 337.751 \text{ ppm}$$

$$i_{data} := 40$$

$$OH_{depcalc_i_{data}} := OH_{dep}$$

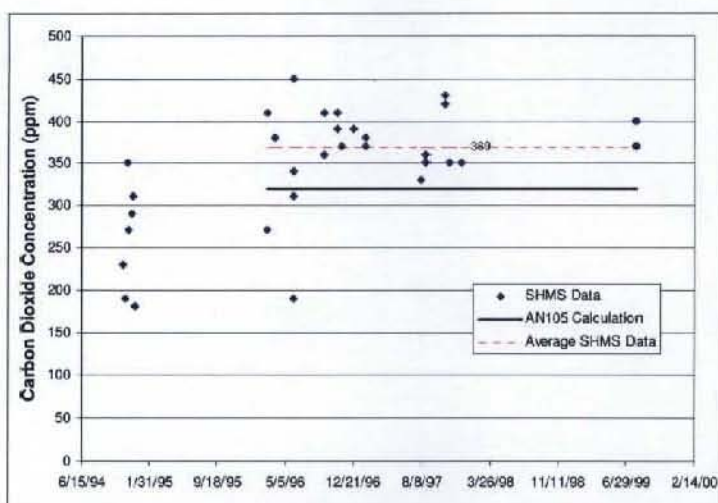
$$CO2_{data} := 369 \text{ ppm}$$

$$OH_{depdata_i_{data}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs_i_{data}} := 2 \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs} \left(OH_{hanford_data2} \right)$$

Figure 5-52. AN-105 Carbon Dioxide Data.



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5.14 TANK AN-106

The waste temperature profiles for the two measurement periods are shown below. The supernatant temperature exceeds the vapor space temperature for both periods.

$$Q_{an6} := 92 \text{ cfm}$$

$$V_{sup_an6} := 38 \text{ kgal}$$

The OH concentration is shown in the figure below.

$$OH_{data} := .22 \text{ M}$$

$$CO3_{an6} := \frac{10000 \frac{\text{mole}}{\text{yr}} \cdot 6 \text{ yr}}{V_{sup_an6}}$$

$$CO3_{an6} = 0.417 \text{ M}$$



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$$Q := Q_{an6}$$

$$T_{sup} := 64F$$

$$\Delta T_{an6} := .01F$$

$$CO3_{bulk} := CO3_{an6}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .80 \cdot OH_{data}$$

$$CO3_{i_guess} := 1.39 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.58 M$$

$$OH_{liq_mass_transfer} := \omega_{OH_{liq}}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 119 \cdot ppm$$

$$OH_{dep} := \omega_{OH_{air}}(\Delta T_{an6}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 118.926 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 2.973 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 2.949 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.452 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.475 \times 10^4 \frac{\text{mole}}{\text{yr}}$$



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$$\frac{OH_{dep}}{2} = 1.475 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$F_{an6} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{an6} = 0.67$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{an6})$$

$$C_{co2} = 135.443 \text{ ppm}$$

$$i_{data} := 41$$

$$OH_{depcalc, i_{data}} := OH_{dep}$$

$$CO2_{data} := 190 \text{ ppm}$$

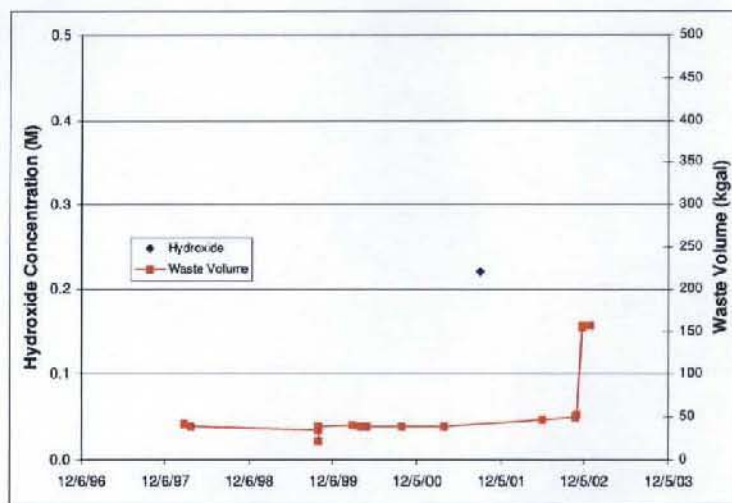
$$OH_{depdata, i_{data}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs, i_{data}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

$$OH_{data, an6} := OH_{data}$$

Figure 5-53. AN-106 Waste Volume and Hydroxide Data.



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Figure 5-54. AN-106 Waste Temperature Profile.

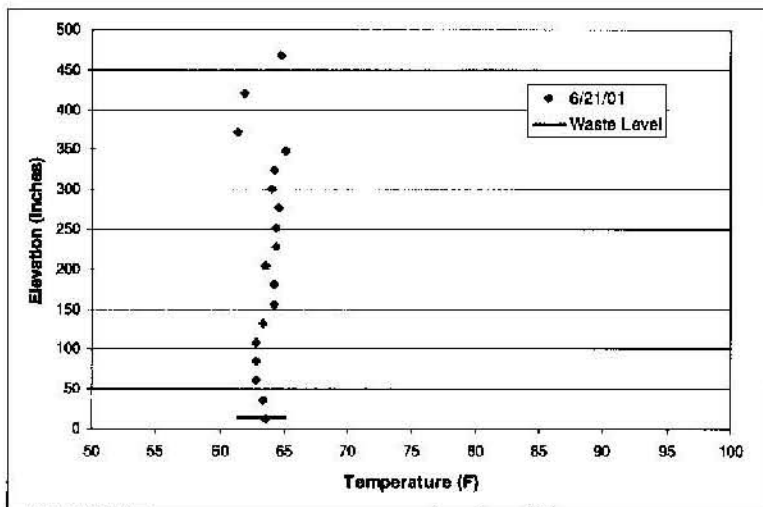
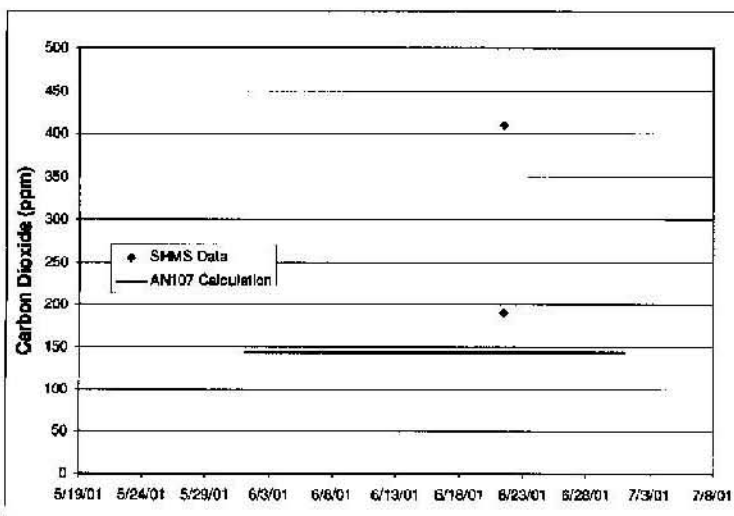


Figure 5-55. AN-106 Carbon Dioxide Data.



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5.14 TANK AN-107

$$Q_{an7} := 92 \text{ cfm}$$

$$T_{sup_an7} := 85 \text{ F}$$

$$\Delta T_{an7} := 5.4 \text{ F}$$

$$V_{saltcake} := 237 \text{ kgal}$$

$$z_{saltcake} := \frac{V_{saltcake}}{A_{tank}}$$

$$z_{saltcake} = 86.057 \text{ in}$$

$$V_{sup_an7} := (38 \text{ lin} \cdot A_{tank}) - V_{saltcake}$$

$$OH_{data} := \frac{0.002 \text{ M} + .0011 \text{ M}}{2}$$

$$OH_{data} = 1.55 \times 10^{-3} \text{ M}$$

$$OH_{data_an7} := OH_{data}$$

$$\Delta T_{liq} := 0 \text{ F}$$

$$CO3_{an7} := \frac{12000 \frac{\text{mole}}{\text{yr}} \cdot 15 \text{ yr}}{V_{sup_an7}}$$

$$CO3_{an7} = 0.059 \text{ M}$$

$$D_{liq} = 4 \text{ in}$$



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$$Q := Q_{an7}$$

$$T_{sup} := T_{sup_an7}$$

$$CO3_{bulk} := CO3_{an7}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .129 \cdot OH_{data}$$

$$CO3_{i_guess} := 1.22 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.071 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 322 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{an7}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 326.554 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 912.156 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 4.087 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.149 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 2.043 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

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$$\frac{OH_{dep}}{2} = 2.046 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$F_{an7} := \frac{OH_{dep}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{an7} = 0.093$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{an7})$$

$$C_{co2} = 371.908 \text{ ppm}$$

$$i_{data} := 42$$

$$OH_{dep_{calc}_{i_{data}}} := OH_{dep}$$

$$CO2_{data} := 294 \text{ ppm}$$

$$OH_{dep_{data}_{i_{data}}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

$$OH_{dep_{an7}} := OH_{dep}$$

The depletion rate based upon the Hobbs model is

$$OH_{dep_{hobbs}_{i_{data}}} := 2 x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

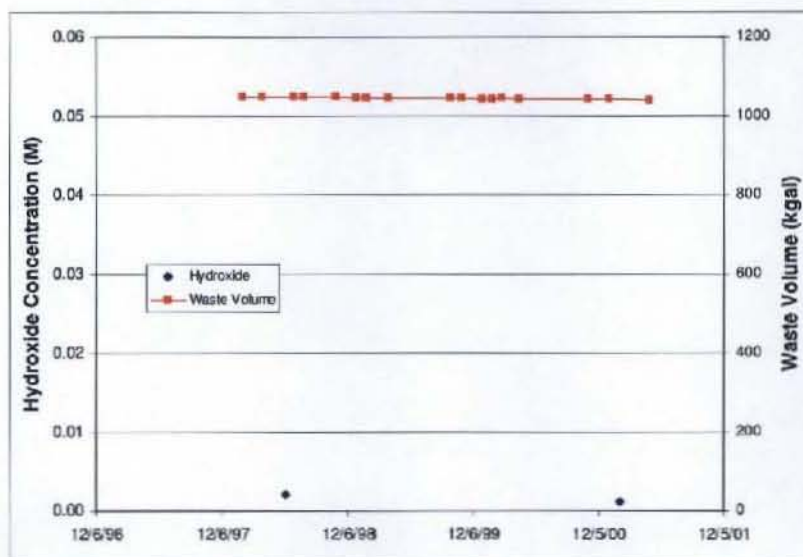


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Figure 5-56. AN-107 Waste Volume and Hydroxide Data.



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Figure 5-57. AN-107 Waste Temperature Profile.

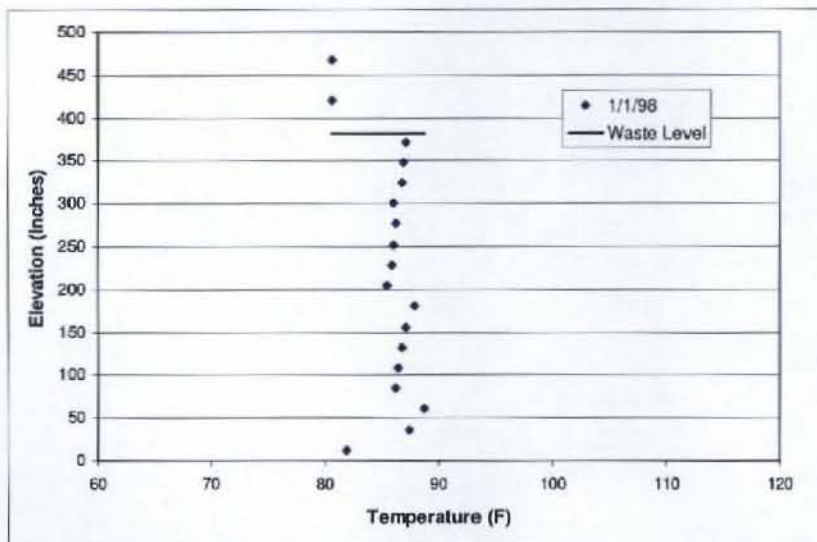
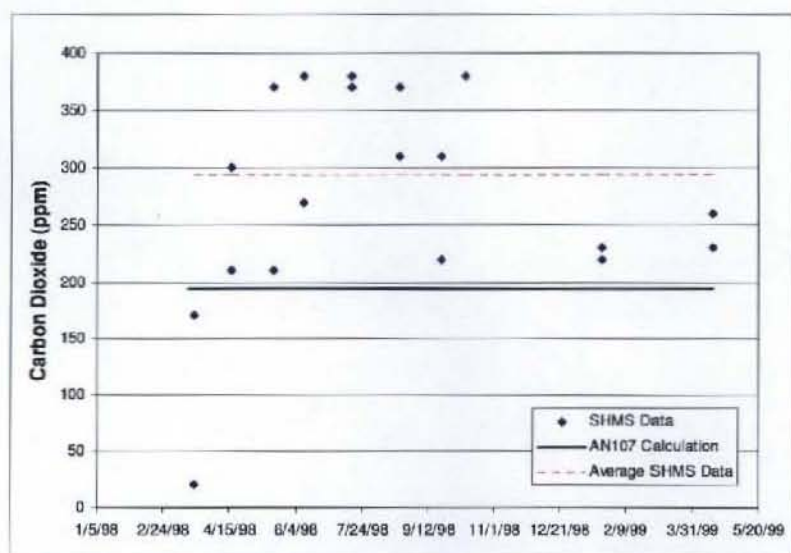
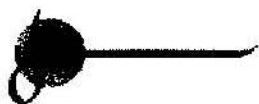


Figure 5-58. AN-107 Carbon Dioxide Data.



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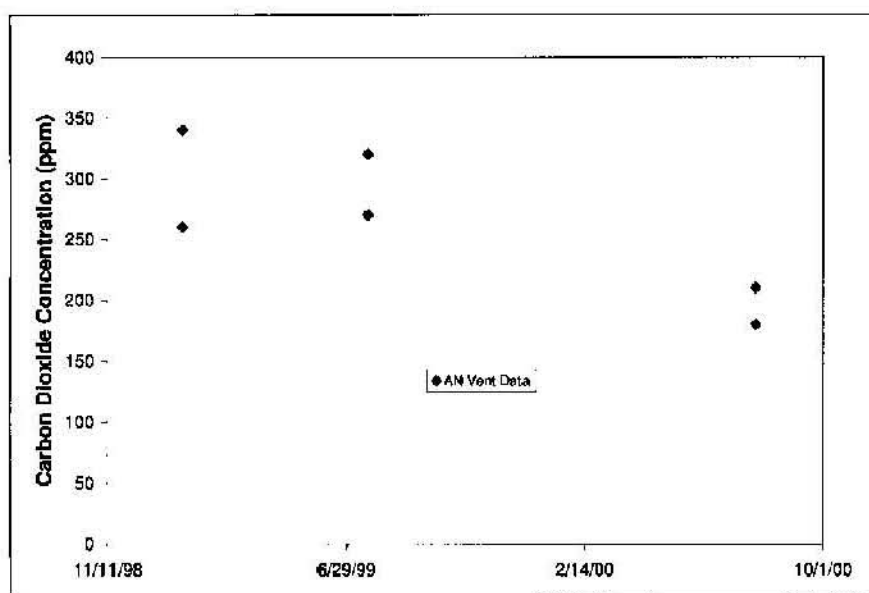
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5.15 AN Ventilation Data

Measurements were obtained for two periods. The first January 1999 to August 1999 and the second July 2000. Both periods will be evaluated.

Figure 5-59. AN-Farm Carbon Dioxide Data.





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5.15.1 Tank AN-101

There temperature profiles for Periods 1 and two are shown below. The 2nd and 3rd TCs are used for period 1 to estimate the supernatant/ vapor space temperature difference, which is shown below. The vapor space is hotter than the supernatant for much of this period. The 3rd and 4th TCs were used for the second period. The temperatures are shown below. During this period the supernatant temperatures are greater than the vapor space temperature. The analyses for Section 5.10.2 will be used for the first period where the vapor space temperature is greater than the supernatant and the analyses for Section 5.10.1 were the supernatant temperature is greater than the dome will be used for the second period.

$$Q1_{an1} := 92\text{cfm}$$

$$Q2_{an1} := 92\text{cfm}$$

$$OH_{dep1_{an1}} := OH_{depcalc_{37}}$$

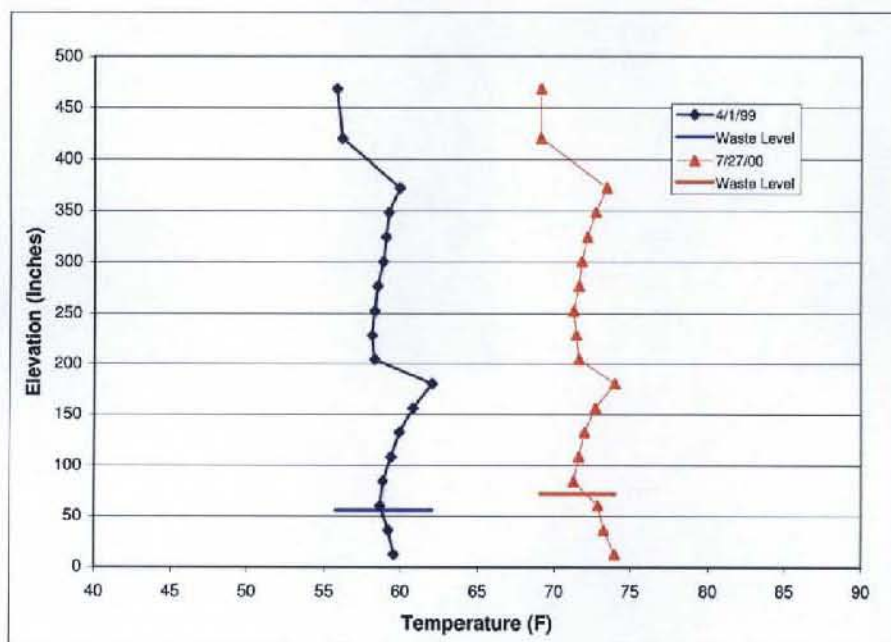
The depletion rate based upon the Hobbs model is

$$OH_{hobbs1_{an1}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{dataan1_2})$$

The depletion rate based upon the Hobbs model is

$$OH_{hobbs2_{an1}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{dataan1_1})$$

Figure 5-60. AN-101 April 1999 July 2000 Waste Temperature Profiles.

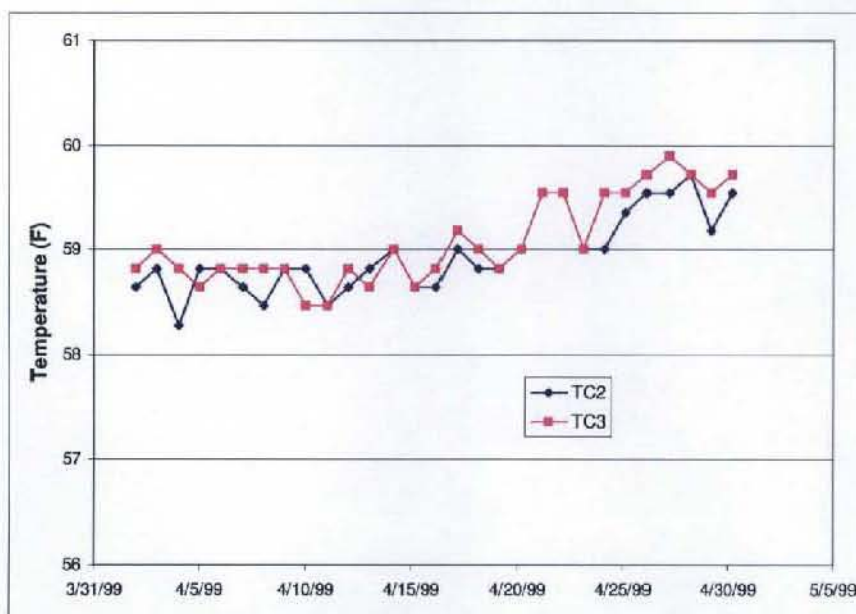
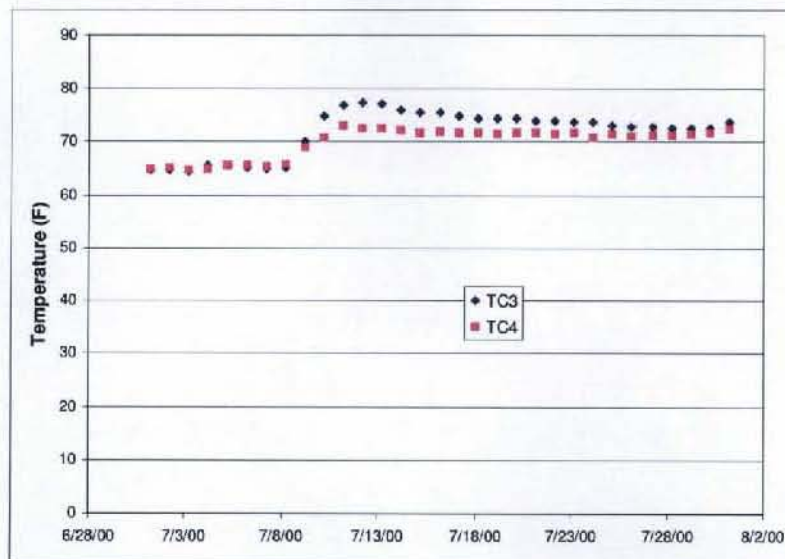




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Figure 5-61. AN-101 April 1999 Vapor Space and Supernatant Temperatures.**Figure 5-62. AN-101 July 2000 Vapor Space and Supernatant Temperatures.**



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$$Q := Q_{2_{an1}}$$

$$T_{sup} := 70F$$

$$\Delta T_{an1} := 1F$$

$$CO3_{bulk} := CO3_{an1}$$

$$OH_{data} := .4M$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .887 \cdot OH_{data}$$

$$CO3_{i_guess} := 1.39 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.702 M$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 35.5 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{an1}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 33.101 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.054 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 3.999 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.757 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 2 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$OH_{dep2_{an1}} := \frac{OH_{dep}}{2}$$

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5.15.2 TANK AN-102

The waste temperature profiles for the two measurement periods are shown below. The supernatant temperature exceeds the vapor space temperature for both periods.

$$\Delta T_{an2} := 2F$$

$$Q1_{an2} := 92\text{cfm}$$

$$Q2_{an2} := 92\text{cfm}$$

$$V_{sup_an2} := 1050\text{kgal}$$

$$T_{sup_an2} := 85F$$

The OH concentration is shown in the figure below.

$$OH_{data} := .176M$$

$$CO3_{an2} := \frac{20000 \frac{\text{mole}}{\text{yr}} \cdot 15\text{yr}}{V_{sup_an2}}$$

$$CO3_{an2} = 0.075M$$



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$$Q := Q_{I_{an2}}$$

$$T_{sup} := T_{sup_{an2}}$$

$$CO3_{bulk} := CO3_{an2}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .67 \cdot OH_{data}$$

$$CO3_{i_guess} := 3.9 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.294 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_{liq}}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_{liq}} := \omega_{CO2_{liq}}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 29.8 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_{air}}(\Delta T_{an2}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 29.625 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.924 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_{liq}}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 4.042 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.953 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 2.021 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$OH_{dep_{an2}} := OH_{dep}$$

$$OH_{hobbs_{an2}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$



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$$Q := Q_{an2}$$

$$T_{sup} := T_{sup_an2}$$

$$CO3_{bulk} := CO3_{an2}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .12 \cdot OH_{data}$$

$$CO3_{i_guess} := 4 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.302 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 30\text{-ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{an2}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 28.709 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.046 \times 10^5 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 4.053 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 2.021 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 2.026 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$OH_{dep2_an2} := OH_{dep}$$

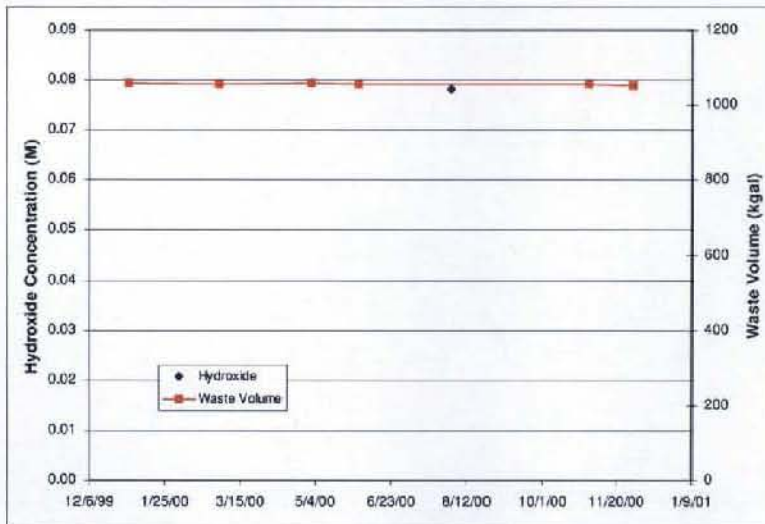
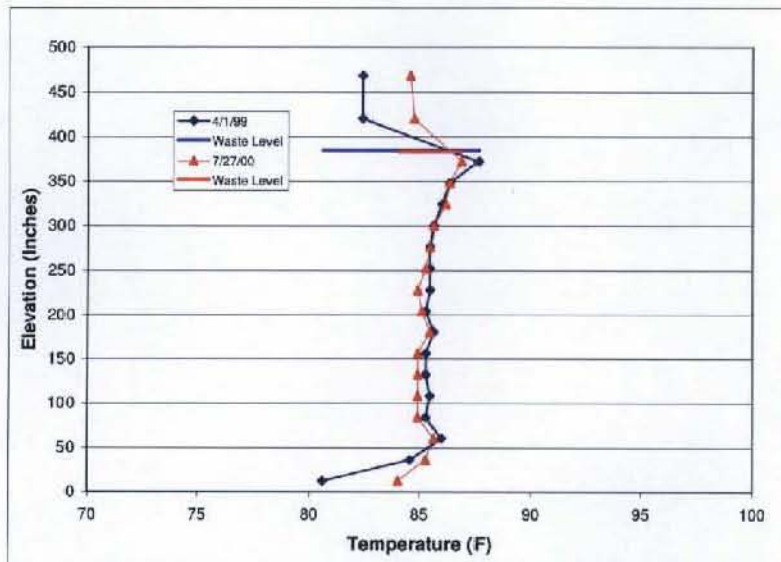
$$OH_{hobbs2_an2} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$



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Figure 5-63. AN-102 Waste Volume and Hydroxide Data.**Figure 5-64. AN-102 April 1999 and July 2000 Waste Temperature Profile.**



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5.15.3 Tank AN-103

There temperature profiles for Periods 1 and two are shown below. The analyses for Section 5.11 will be used.

$$Q1_{an3} := 132 \text{ cfm}$$

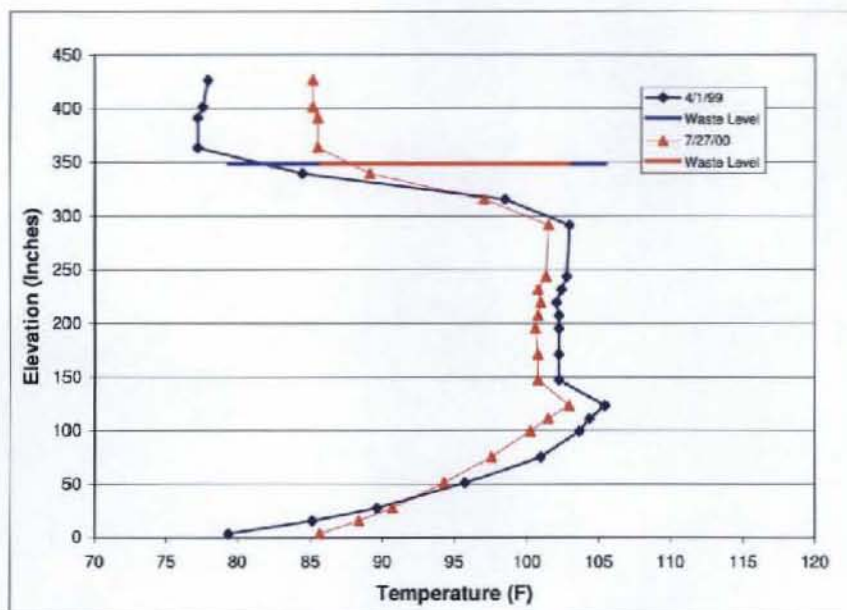
$$Q2_{an3} := 132 \text{ cfm}$$

$$OHdep1_{an3} := OHdep_{an3}$$

The depletion rate based upon the Hobbs model is

$$OHhobbs1_{an3} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OHdata_{an3})$$

Figure 5-65. AN-103 April 1999 and July 2000 Waste Temperature Profile.





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$$Q := Q_{2_{an3}}$$

$$T_{sup} := T_{sup_{an3}}$$

$$CO3_{bulk} := CO3_{an3}$$

$$OH_{data} := 5M$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .000377 \cdot OH_{data}$$

$$CO3_{i_guess} := 161 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 6.098 M$$

$$OH_{liq_mass_transfer} := \omega_{OH_{liq}}(\Delta T_{liq}, T_{sup}, L_{crust_{an3}}, E \cdot A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, L_{crust_{an3}}, E \cdot A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_{liq}}(\Delta T_{liq}, T_{sup}, L_{crust_{an3}}, E \cdot A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 313ppm$$

$$OH_{dep} := \omega_{OH_{air}}(\Delta T_{an3}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 315.342 ppm$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 7.204 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 7.839 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.154 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 3.919 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$OH_{dep2_{an3}} := OH_{dep}$$



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5.15.4 Tank AN-104

There temperature profiles for Periods 1 and two are shown below. The analyses for Section 3.1.1 will be used.

$$Q1_{an4} := 132 \text{ cfm}$$

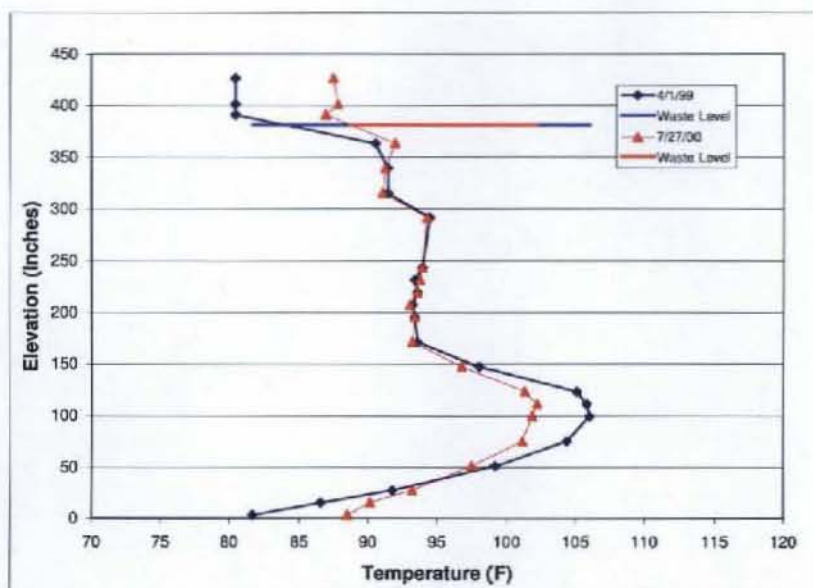
$$Q2_{an4} := 132 \text{ cfm}$$

$$OH_{dep1_{an4}} := OH_{dep_{an4}}$$

The depletion rate based upon the Hobbs model is

$$OH_{hobbs1_{an4}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{hanford_data_1})$$

Figure 5-66. AN-104 April 1999 and July 2000 Waste Temperature Profile.





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$$Q := Q_{2_{an4}}$$

$$T_{sup} := T_{supernate_i}$$

$$OH_{data} := OH_{hanford_data_i}$$

$$CO3_{bulk} := CO3_i$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .000554 \cdot OH_{data}$$

$$CO3_{i_guess} := 88 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 7.66 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_{liq}}(\Delta T_{liq}, T_{sup}, L_{crust_an4}, E \cdot A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, L_{crust_an4}, E \cdot A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, L_{crust_an4}, E \cdot A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 297 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_{air}}(\Delta T_{hanford_i}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 280.192 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.066 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

$$OH_{dep_surface} = 1.401 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 2.703 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 7.004 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$OH_{dep2_{an4}} := OH_{dep}$$



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5.15.5 Tank AN-105

There temperature profiles for Periods 1 and two are shown below. The analyses for Section 3.1.2 will be used.

$$Q1_{an5} := 132 \text{ cfm}$$

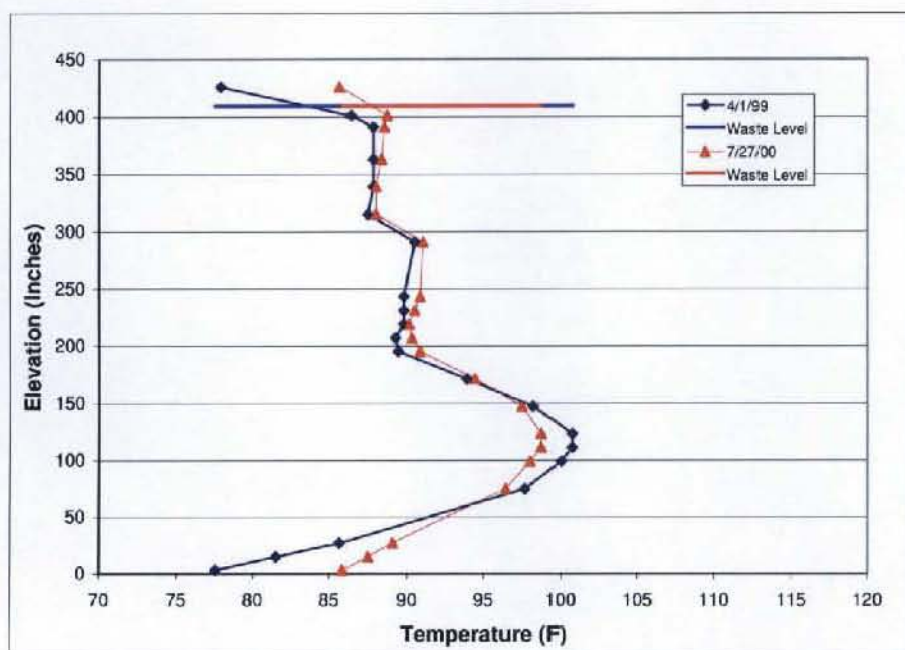
$$Q2_{an5} := 132 \text{ cfm}$$

$$OH_{dep1_{an5}} := OH_{dep_{an5}}$$

The depletion rate based upon the Hobbs model is

$$OH_{hobbs1_{an5}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{hanford_data_2})$$

Figure 5-67. AN-105 April 1999 and July 2000 Waste Temperature Profile.





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$$Q := Q_{2_{an5}}$$

$$T_{sup} := T_{supernate_2}$$

$$OH_{data} := OH_{hanford_data_2}$$

$$CO3_{bulk} := CO3_2$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .000365 \cdot OH_{data}$$

$$CO3_{i_guess} := 159 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 2.857 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, L_{crust_an5}, E \cdot A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, L_{crust_an5}, E \cdot A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, L_{crust_an5}, E \cdot A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 286.5 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{hanford_2}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 288.097 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 1.058 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 1.262 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.067 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 6.31 \times 10^3 \frac{\text{mole}}{\text{yr}}$$

$$OH_{dep2_{an5}} := OH_{dep}$$

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5.15.6 Tank AN-106

$$Q1_{an6} := 92 \text{ cfm}$$

$$Q2_{an6} := 92 \text{ cfm}$$

$$OH_{dep1_{an6}} := OH_{dcpsk}_{41}$$

The depletion rate based upon the Hobbs model is

$$OH_{hobbs1_{an6}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data_{an6}})$$



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$$Q := Q_{an6}$$

$$T_{sup} := 64F$$

$$\Delta T_{an6} := .01F$$

$$CO_{3,bulk} := CO_{3,an6}$$

$$OH_{data} := .22M$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .78 \cdot OH_{data}$$

$$CO_{3,i_guess} := 1.45 \cdot CO_{3,bulk}$$

$$CO_{3,i_guess} = 0.605 M$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO_{3_mass_transfer} := \omega_{CO_3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO_{3,bulk}, CO_{3,i_guess})$$

$$CO_{2_mass_transfer_liq} := \omega_{CO_2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO_{3,bulk}, CO_{3,i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO₂ mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 119 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{an6}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO_{3,i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO₂ concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 118.926 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO₂ absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.27 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$OH_{dep_bulk} := 2 \cdot CO_{2_mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 2.949 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO₃ Mass Transfer Rate

The CO₃ mass transfer rate should be half the surface OH Depletion rate.

$$CO_{3_mass_transfer} = 1.675 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.475 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$OH_{dep2_an6} := OH_{dep}$$



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5.15.7 Tank AN-107

There temperature profiles for Periods 1 and two are shown below. The analyses for Section 5.1.4 will be used.

$$Q1_{an7} := 92\text{cfm}$$

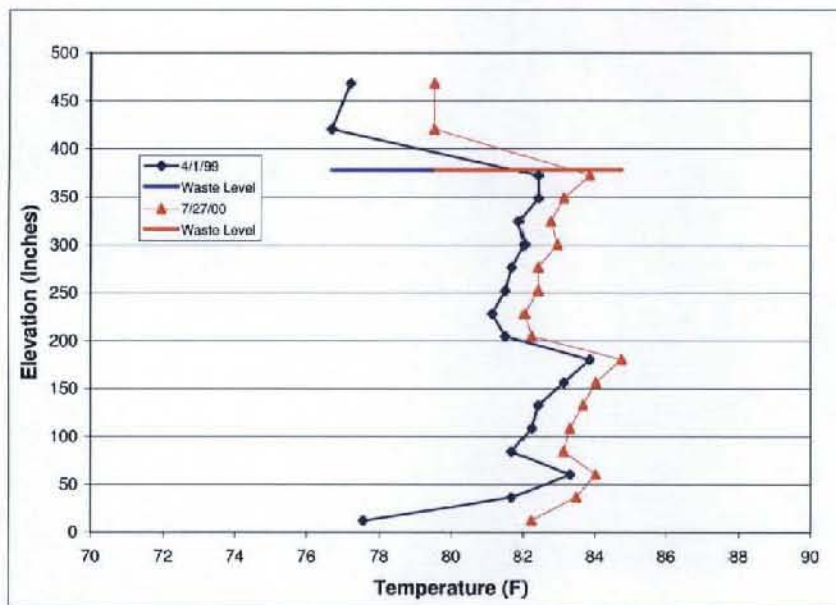
$$Q2_{an7} := 92\text{cfm}$$

$$OHdep1_{an7} := OHdep_{an7}$$

The depletion rate based upon the Hobbs model is

$$OHhobbs1_{an7} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OHdata_{an7})$$

Figure 5-68. AN-107 April 1999 and July 2000 Waste Temperature Profile.





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$$Q := Q_{an7}^2$$

$$T_{sup} := T_{sup_an7}$$

$$CO3_{bulk} := CO3_{an7}$$

$$OH_{data} := 0.043M$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .011 \cdot OH_{data}$$

$$CO3_{i_guess} := 3.3 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.193M$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 167 \cdot ppm$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{an7}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 168.491 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 2.873 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 2.343 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.202 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.171 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$OH_{dep2_an7} := OH_{dep}$$

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5.15.8 AN Vent Results

$$Q_{an} := Q1_{an1} + Q1_{an2} + Q1_{an3} + Q1_{an4} + Q1_{an5} + Q1_{an6} + Q1_{an7}$$

Period 1

$$i_{data} := 43$$

$$OH_{depcalc, i_{data}} := OHdep1_{an1} + OHdep1_{an2} + OHdep1_{an3} + OHdep1_{an4} + OHdep1_{an5} + OHdep1_{an6} + OHdep1_{an7}$$

$$CO2_{data} := 298 \text{ ppm}$$

$$OH_{depdata, i_{data}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{an} \cdot 2$$

$$F_{an} := \frac{OH_{depcalc, i_{data}}}{2 \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{an}}$$

$$F_{an} = 0.32$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{an})$$

$$C_{co2} = 278.74 \text{ ppm}$$

$$OH_{dephobbs, i_{data}} := OHhobbs1_{an1} + OHhobbs1_{an2} + OHhobbs1_{an3} + OHhobbs1_{an4} + OHhobbs1_{an5} + OHhobbs1_{an6} + OHhobbs1_{an7}$$

Period 2

$$i_{data} := 44$$

$$OH_{depcalc, i_{data}} := OHdep2_{an1} + OHdep2_{an2} + OHdep2_{an3} + OHdep2_{an4} + OHdep2_{an5} + OHdep2_{an6} + OHdep2_{an7}$$

$$CO2_{data} := 195 \text{ ppm}$$

$$OH_{depdata, i_{data}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{an} \cdot 2$$

$$F_{an} := \frac{OH_{depcalc, i_{data}}}{2 \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{an}}$$

$$F_{an} = 0.404$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{an})$$

$$C_{co2} = 244.184 \text{ ppm}$$

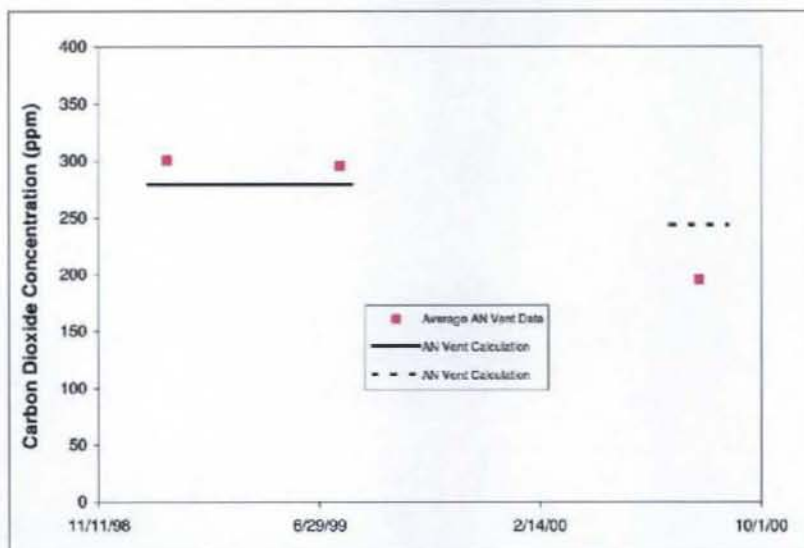
$$OH_{dephobbs, i_{data}} := OHdep1_{an1} + OHdep1_{an2} + OHdep1_{an3} + OHdep1_{an4} + OHdep1_{an5} + OHdep1_{an6} + OHdep1_{an7}$$



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Figure 5-69. AN-Farm Carbon Dioxide Data.

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5.18 TANK AP-101

$$Q_{ap1} := Q_{vent4}$$

$$Q_{ap1} = 111 \text{ cfm}$$

$$T_{sup_ap1} := 65\text{F}$$

$$\Delta T_{ap1} := 0.01\text{F}$$

$$V_{saltcake} := 0 \text{ kgal}$$

$$z_{saltcake} := \frac{V_{saltcake}}{A_{tank}}$$

$$z_{saltcake} = 0 \text{ in}$$

$$V_{sup_ap1} := (404.9 \text{ in} \cdot A_{tank}) - V_{saltcake}$$

$$OH_{data} := 2.5\text{M}$$

$$\Delta T_{liq} := 0\text{F}$$

$$CO3_{ap1} := \frac{25000 \frac{\text{mole}}{\text{yr}} \cdot 15 \text{ yr}}{V_{sup_ap1}}$$

$$CO3_{ap1} = 0.089\text{M}$$

$$D_{liq} = 4 \text{ in}$$



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$$Q := Q_{ap1}$$

$$T_{sup} := T_{sup_ap1}$$

$$CO3_{bulk} := CO3_{ap1}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .980 \cdot OH_{data}$$

$$CO3_{i_guess} := 3 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.267 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 134 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{ap1}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 135.802 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.378 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 3.309 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.586 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.655 \times 10^4 \frac{\text{mole}}{\text{yr}}$$



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$$\frac{OH_{dep}}{2} = 1.655 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$F_{ap1} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{ap1} = 0.623$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{ap1})$$

$$C_{co2} = 154.663 \text{ ppm}$$

$$CO2_{ap1} := C_{co2}$$

$$OH_{dep_{ap1}} := OH_{dep}$$

$$i_{data} := 45$$

$$OH_{depcalc_{i_{data}}} := OH_{dep}$$

$$CO2_{data} := 250 \text{ ppm}$$

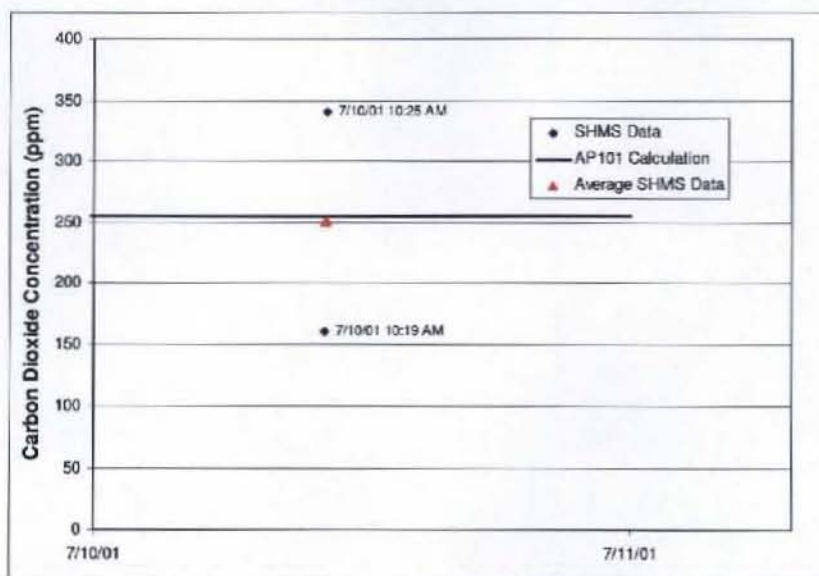
$$OH_{dep_{data_{i_{data}}}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs_{i_{data}}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

$$OH_{hobbs_{ap1}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

Figure 5-70. AP-101 Carbon Dioxide Data.

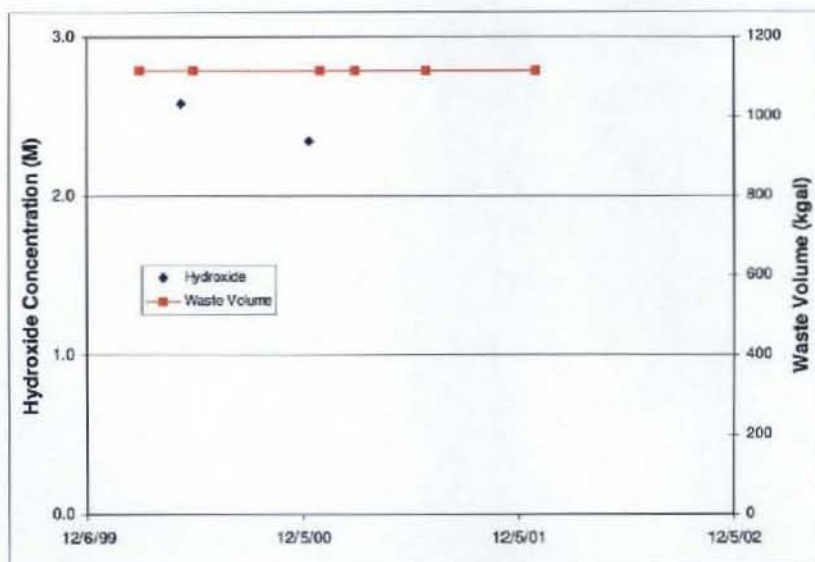
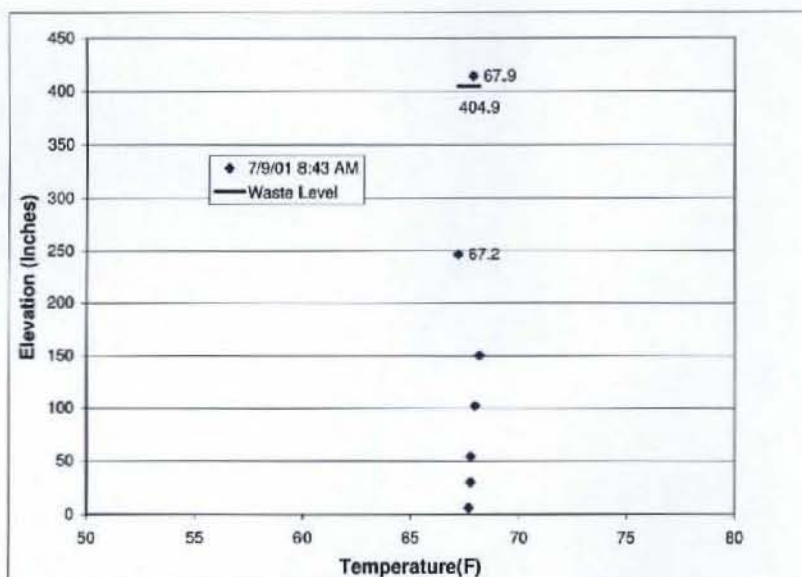




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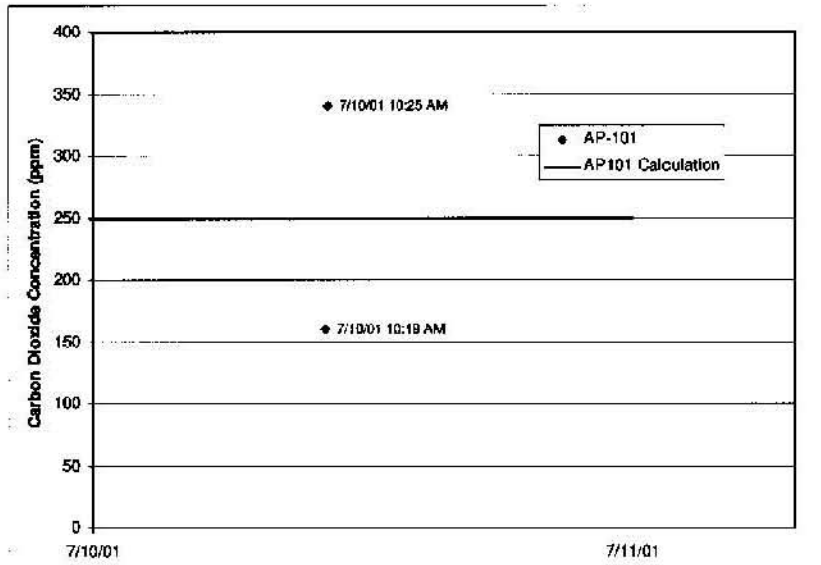
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Figure 5-71. AP-101 Waste Volume and Hydroxide Data.**Figure 5-72. AP-101 7/9/01 Waste Temperature Profile.**

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Figure 5-73. AP-101 Carbon Dioxide Data.

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5.19 TANK AP-102

$$Q_{ap2} := Q_{vent4}$$

$$Q_{ap2} = 111 \text{ cfm}$$

$$T_{sup_ap2} := 65F$$

$$\Delta T_{ap2} := .01F$$

$$V_{saltcake} := 0 \text{ kgal}$$

$$z_{saltcake} := \frac{V_{saltcake}}{A_{tank}}$$

$$z_{saltcake} = 0 \text{ in}$$

$$V_{sup_ap2} := (404.9 \text{ in} \cdot A_{tank}) - V_{saltcake}$$

$$OH_{data} := 0.53 \cdot M - 2 \cdot \frac{26000 \cdot \frac{\text{mole}}{\text{yr}} \cdot 10 \text{ yr}}{V_{sup_ap2}}$$

$$OH_{data} = 0.407 M$$

$$\Delta T_{liq} := 0F$$

$$CO3_{ap2} := \frac{20000 \cdot \frac{\text{mole}}{\text{yr}} \cdot 15 \text{ yr}}{V_{sup_ap2}}$$

$$CO3_{ap2} = 0.071 M$$

$$D_{liq} = 4 \text{ in}$$



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$$Q := Q_{ap2}$$

$$T_{sup} := T_{sup_ap2}$$

$$CO3_{bulk} := CO3_{ap2}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .879 \cdot OH_{data}$$

$$CO3_{i_guess} := 3.5 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.249 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 134 \cdot \text{ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{ap2}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 135.802 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.326 \times 10^{-4} \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 3.309 \times 10^{-4} \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.586 \times 10^{-4} \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.655 \times 10^{-4} \frac{\text{mole}}{\text{yr}}$$

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$$\frac{OH_{dep}}{2} = 1.655 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$F_{ap2} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{ap2} = 0.623$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{ap2})$$

$$C_{co2} = 154.664 \text{ ppm}$$

$$CO2_{ap2} := C_{co2}$$

$$OH_{dep_{ap2}} := OH_{dep}$$

$$i_{data} := 46$$

$$OH_{dep_{calc}_{i_{data}}} := OH_{dep}$$

$$CO2_{data} := 230 \text{ ppm}$$

$$OH_{dep_{data}_{i_{data}}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

The depletion rate based upon the Hobbs model is

$$OH_{dep_{hobbs}_{i_{data}}} := 2 x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

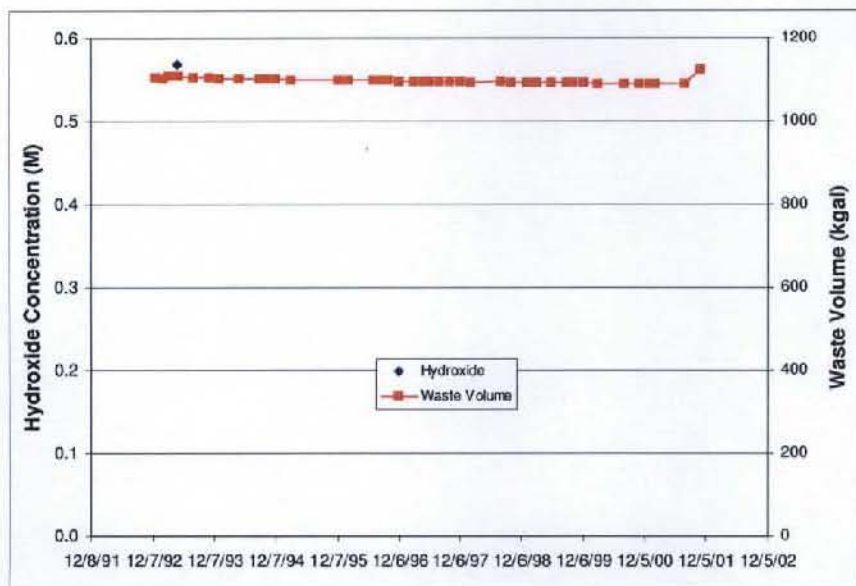
$$OH_{hobbs_{ap2}} := 2 x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$



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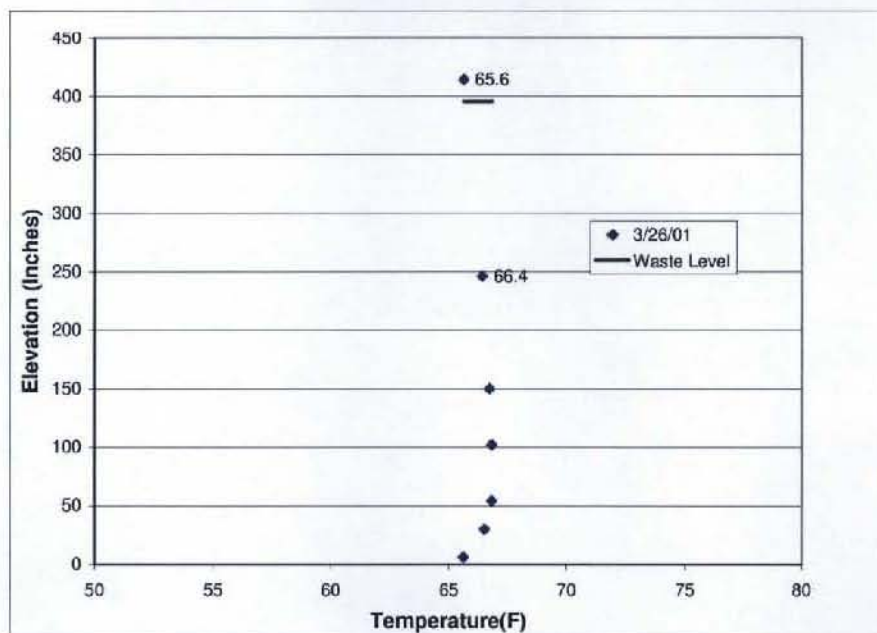
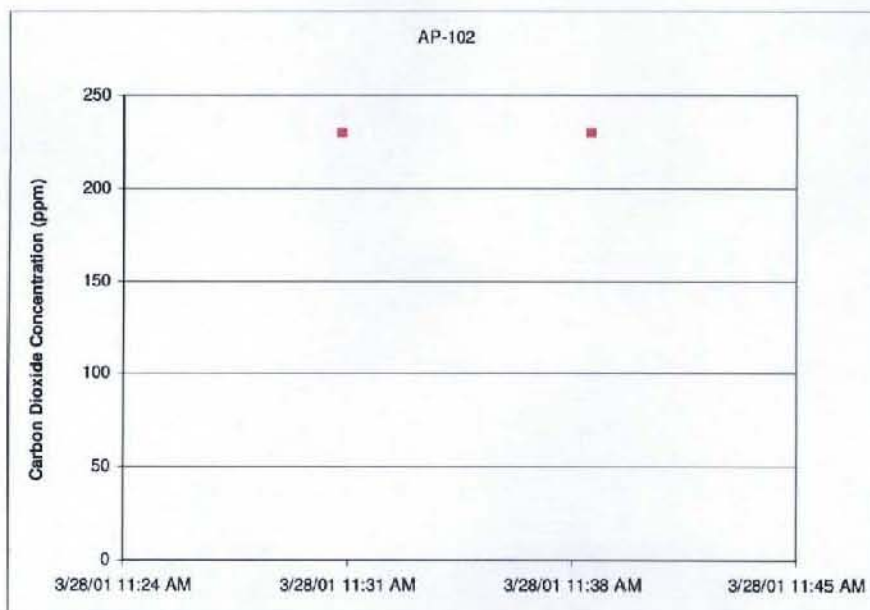
Figure 5-74. AP-102 Waste Volume and Hydroxide Data.



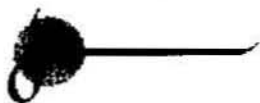
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Figure 5-75. AP-102 3/28/01 Waste Temperature Profile.**Figure 5-76. AP-102 Carbon Dioxide Data.**

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5.20 TANK AP-103

$$Q_{ap3} := Q_{vent_4}$$

$$Q_{ap3} = 111 \text{ cfm}$$

$$T_{sup_ap3} := 65F$$

$$\Delta T_{ap3} := 0.01F$$

$$V_{saltcake} := 0 \text{ kgal}$$

$$z_{saltcake} := \frac{V_{saltcake}}{A_{tank}}$$

$$z_{saltcake} = 0 \text{ in}$$

$$V_{sup_ap3} := 284 \text{ kgal} - V_{saltcake}$$

$$OH_{data} := 0.59M$$

$$\Delta T_{liq} := 0F$$

$$CO3_{ap3} := \frac{10000 \frac{\text{mole}}{\text{yr}} \cdot 15 \text{ yr}}{V_{sup_ap3}}$$

$$CO3_{ap3} = 0.14 M$$

$$D_{liq} = 4 \text{ in}$$



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$$Q := Q_{ap3}$$

$$T_{sup} := T_{sup_ap3}$$

$$CO3_{bulk} := CO3_{ap3}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .912 \cdot OH_{data}$$

$$CO3_{i_guess} := 2.3 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.321 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 134 \cdot \text{ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{ap3}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 135.802 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.508 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 3.309 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.619 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.655 \times 10^4 \frac{\text{mole}}{\text{yr}}$$



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$$\frac{OH_{dep}}{2} = 1.655 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$F_{ap3} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{ap3} = 0.623$$

$$C_{co2} := x_{co2_pnm} \cdot (1 - F_{ap3})$$

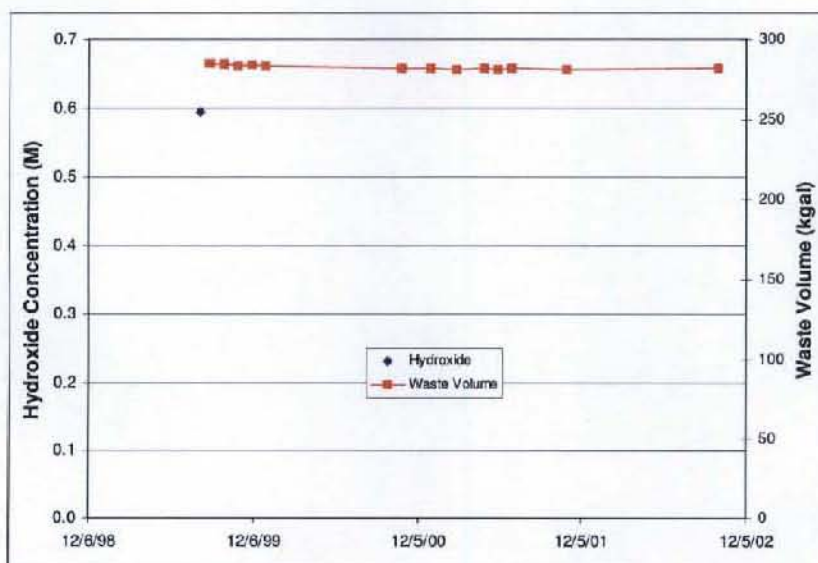
$$C_{co2} = 154.664 \text{ ppm}$$

$$CO2_{ap3} := C_{co2}$$

$$OH_{dep_{ap3}} := OH_{dep}$$

$$OH_{hobbs_{ap3}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

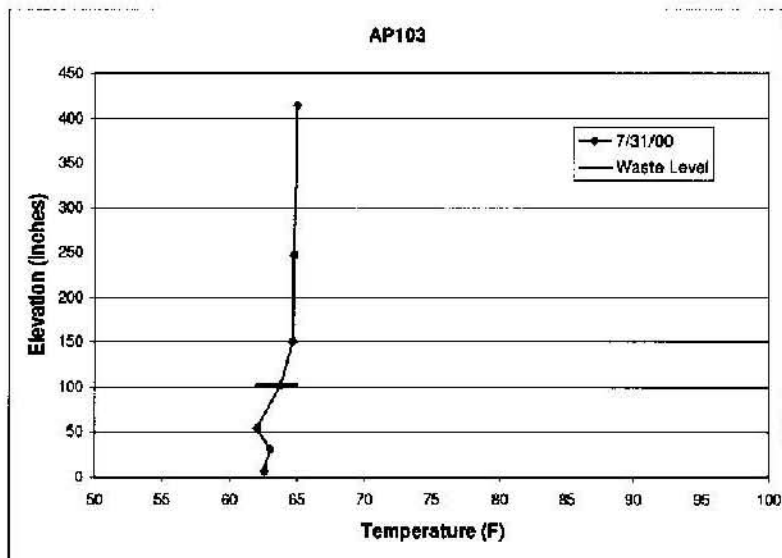
Figure 5-77. AP-103 Waste Volume and Hydroxide Data.



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Figure 5-78. AP-103 7/31/00 Waste Temperature Profile.

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5.21 TANK AP-104

$$Q_{ap4} := Q_{vent4}$$

$$Q_{ap4} = 111 \text{ cfm}$$

$$T_{sup_ap4} := 75\text{F}$$

$$\Delta T_{ap4} := .011\text{F}$$

$$V_{saltcake} := 89\text{kgal}$$

$$z_{saltcake} := \frac{V_{saltcake}}{A_{tank}}$$

$$z_{saltcake} = 32.317 \text{ in}$$

$$V_{sup_ap4} := (403 \text{ in} \cdot A_{tank}) - V_{saltcake}$$

$$OH_{data} := 1.26 \cdot M$$

$$\Delta T_{liq} := 0\text{F}$$

$$CO3_{ap4} := \frac{20000 \frac{\text{mole}}{\text{yr}} \cdot 15\text{yr}}{V_{sup_ap4}}$$

$$CO3_{ap4} = 0.078 \text{ M}$$

$$D_{liq} = 4 \text{ in}$$



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$$Q := Q_{ap4}$$

$$T_{sup} := T_{sup_ap4}$$

$$CO3_{bulk} := CO3_{ap4}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .9645 \cdot OH_{data}$$

$$CO3_{i_guess} := 3.3 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.256 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 137.5 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{ap4}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 137.561 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.022 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 3.283 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.593 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.642 \times 10^4 \frac{\text{mole}}{\text{yr}}$$



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$$\frac{OH_{dep}}{2} = 1.642 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$F_{ap4} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{ap4} = 0.618$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{ap4})$$

$$C_{co2} = 156.666 \text{ ppm}$$

$$CO2_{ap4} := C_{co2}$$

$$OH_{dep_{ap4}} := OH_{dep}$$

$$i_{data} := 47$$

$$OH_{depcalc_{i_{data}}} := OH_{dep}$$

$$CO2_{data} := 250 \text{ ppm}$$

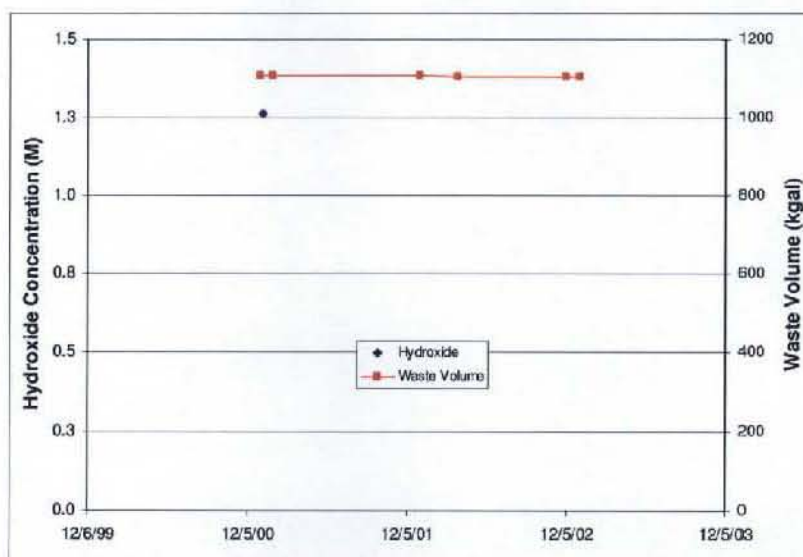
$$OH_{dep_{data_{i_{data}}}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

The depletion rate based upon the Hobbs model is

$$OH_{dephobbs_{i_{data}}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

$$OH_{hobbs_{ap4}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

Figure 5-79. AP-104 Waste Volume and Hydroxide Data.

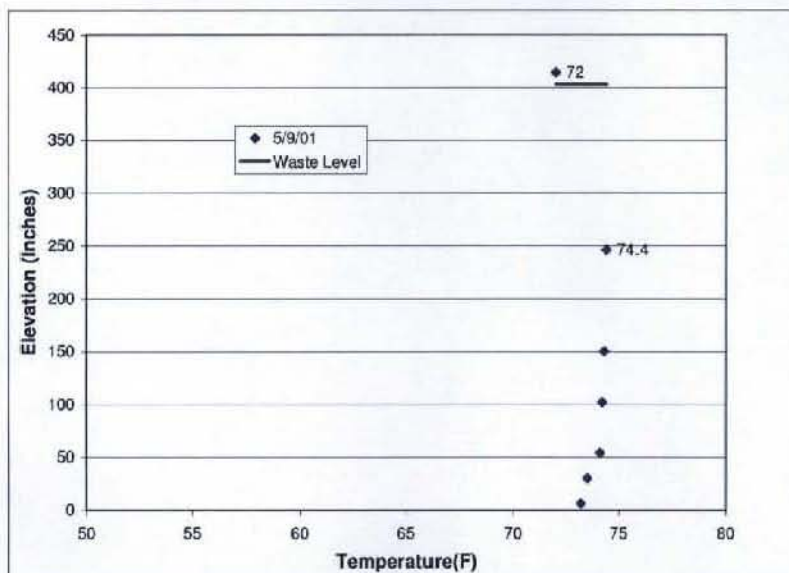
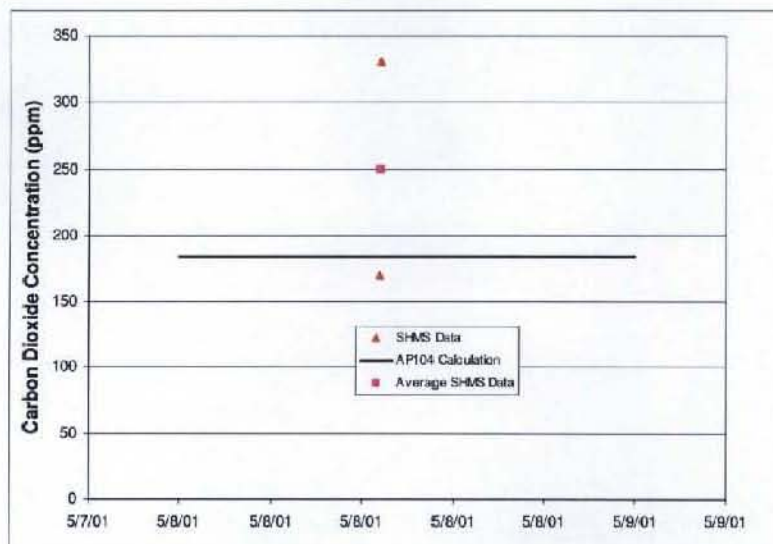




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Figure 5-80. AP-104 5/9/01 Waste Temperature Profile.**Figure 5-81. AP-104 Carbon Dioxide Data.**

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5.22 TANK AP-105

$$Q_{ap5} := Q_{vent4}$$

$$Q_{ap5} = 111 \text{ cfm}$$

$$T_{sup_ap5} := 65\text{F}$$

$$\Delta T_{ap5} := .01\text{F}$$

$$V_{saltcake} := 89\text{kgal}$$

$$z_{saltcake} := \frac{V_{saltcake}}{A_{tank}}$$

$$z_{saltcake} = 32.317 \text{ in}$$

$$V_{sup_ap5} := 1132\text{kgal} - V_{saltcake}$$

$$OH_{data} := 2.2 \cdot M$$

$$\Delta T_{liq} := 0\text{F}$$

$$CO3_{ap5} := \frac{17000 \frac{\text{mole}}{\text{yr}} \cdot 20\text{yr}}{V_{sup_ap5}}$$

$$CO3_{ap5} = 0.086\text{M}$$

$$D_{liq} = 4 \text{ in}$$



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$$Q := Q_{ap5}$$

$$T_{sup} := T_{sup_ap5}$$

$$CO3_{bulk} := CO3_{ap5}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .978 \cdot OH_{data}$$

$$CO3_{i_guess} := 3.3 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.284 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 135 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{ap5}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 134.129 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.27 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 3.334 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.767 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.667 \times 10^4 \frac{\text{mole}}{\text{yr}}$$



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$$\frac{OH_{dep}}{2} = 1.667 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$F_{ap5} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{ap5} = 0.627$$

$$OH_{dep_{ap5}} := OH_{dep}$$

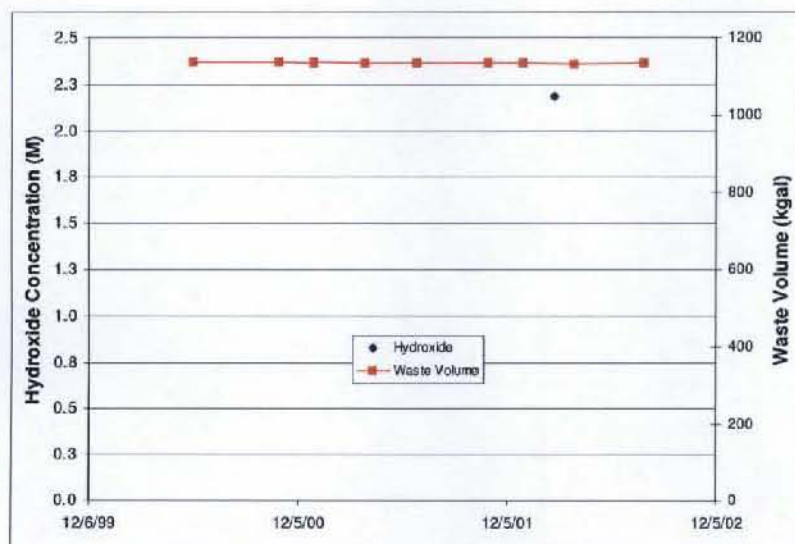
$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{ap5})$$

$$C_{co2} = 152.758 \text{ ppm}$$

$$CO2_{ap5} := C_{co2}$$

$$OH_{hobbs_{ap3}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

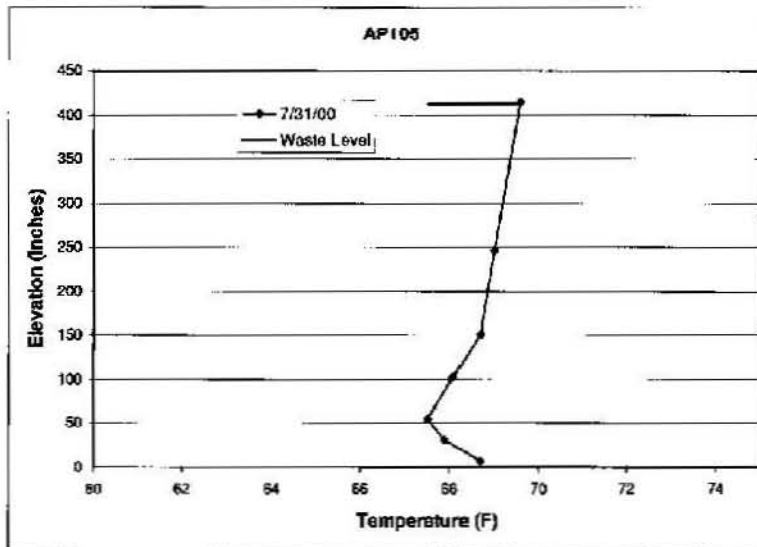
Figure 5-82. AP-105 Waste Volume and Hydroxide Data.



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Figure 5-83. AP-105 7/31/00 Waste Temperature Profile.



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5.23 TANK AP-106

$$Q_{ap6} := Q_{vent_4}$$

$$Q_{ap6} = 111 \text{ cfm}$$

$$T_{sup_ap6} := 75\text{F}$$

$$\Delta T_{ap6} := .01\text{F}$$

$$V_{saltcake} := 89\text{kgal}$$

$$z_{saltcake} := \frac{V_{saltcake}}{A_{tank}}$$

$$z_{saltcake} = 32.317 \text{ in}$$

$$V_{sup_ap6} := (403\text{in} \cdot A_{tank}) - V_{saltcake}$$

$$OH_{data} := 1.24 \cdot M$$

$$\Delta T_{liq} := 0\text{F}$$

$$CO3_{ap6} := \frac{20000 \frac{\text{mole}}{\text{yr}} \cdot 15\text{yr}}{V_{sup_ap6}}$$

$$CO3_{ap6} = 0.078 \text{ M}$$

$$D_{liq} = 4 \text{ in}$$

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$$Q := Q_{ap6}$$

$$T_{sup} := T_{sup_ap6}$$

$$CO3_{bulk} := CO3_{ap6}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .963 \cdot OH_{data}$$

$$CO3_{i_guess} := 3.3 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.256 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 137.5 \text{ ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{ap6}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 137.561 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.1 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 3.283 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.593 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.642 \times 10^4 \frac{\text{mole}}{\text{yr}}$$



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$$\frac{OH_{dep}}{2} = 1.642 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$F_{ap6} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{ap6} = 0.618$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{ap6})$$

$$C_{co2} = 156.666 \text{ ppm}$$

$$CO2_{ap6} := C_{co2}$$

$$OH_{dep_{ap6}} := OH_{dep}$$

$$i_{data} := 48$$

$$OH_{dep_{calc}_{i_{data}}} := OH_{dep}$$

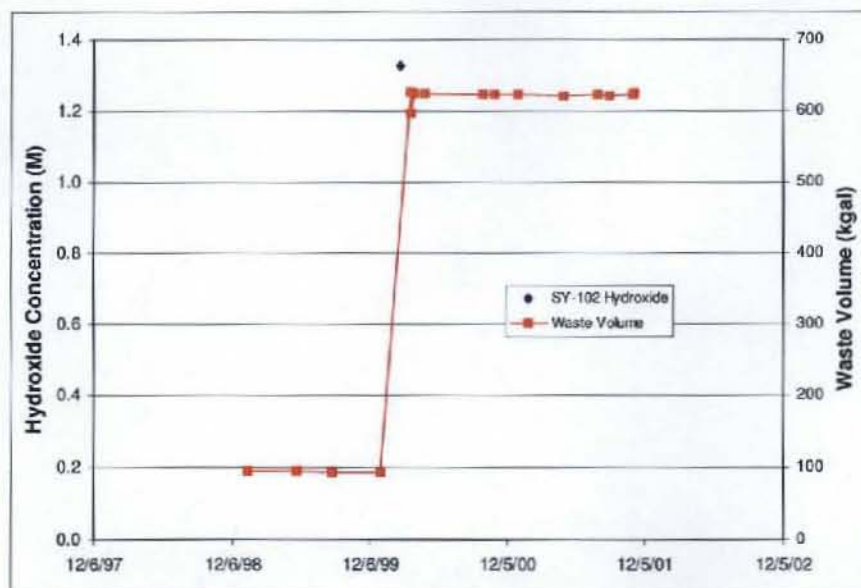
$$CO2_{data} := 155 \text{ ppm}$$

$$OH_{dep_{data}_{i_{data}}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}}\right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q \cdot 2$$

$$OH_{dephobbs_{i_{data}}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

$$OH_{hobbs_{ap6}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

Figure 5-84. SY-102 Waste Volume and Hydroxide Data.





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Figure 5-85. AP-106 11/27/00 Waste Temperature Profile.

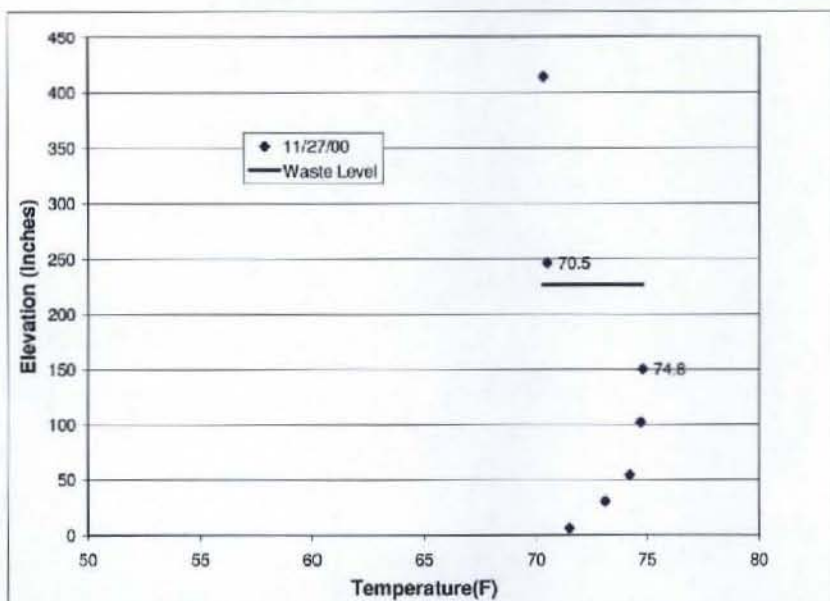
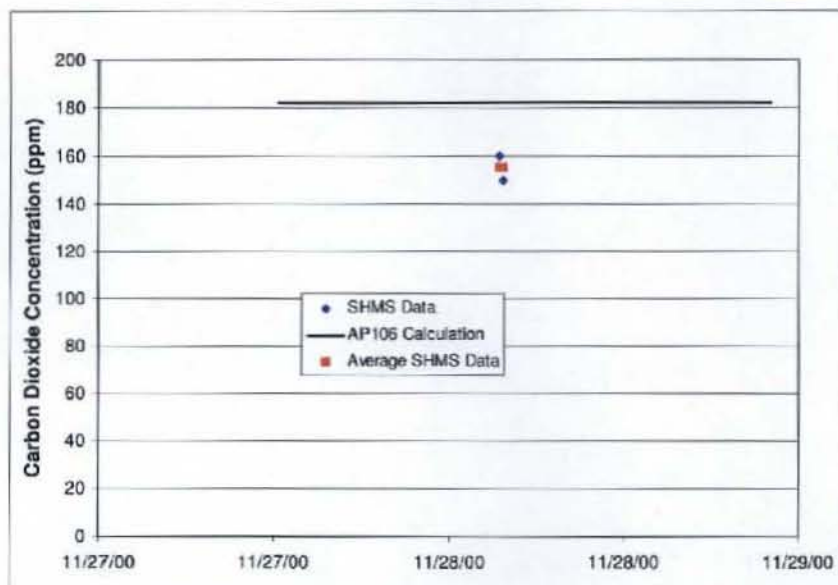
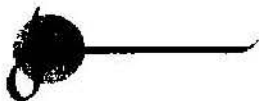


Figure 5-86. AP-106 Carbon Dioxide Data.



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5.24 TANK AP-107

$$Q_{ap7} := Q_{vent_4}$$

$$Q_{ap7} = 111 \text{ cfm}$$

$$T_{sup_ap7} := 65F$$

$$\Delta T_{ap7} := .01F$$

$$V_{saltcake} := 0 \text{ kgal}$$

$$z_{saltcake} := \frac{V_{saltcake}}{A_{tunk}}$$

$$z_{saltcake} = 0 \text{ in}$$

$$V_{sup_ap7} := 1000 \text{ kgal} - V_{saltcake}$$

$$OH_{data} := .6M$$

$$\Delta T_{liq} := 0F$$

$$CO3_{ap7} := \frac{10000 \frac{\text{mole}}{\text{yr}} \cdot 10 \text{ yr}}{V_{sup_ap7}}$$

$$CO3_{ap7} = 0.026 M$$

$$D_{liq} = 4 \text{ in}$$



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$$Q := Q_{ap7}$$

$$T_{sup} := T_{sup_ap7}$$

$$CO3_{bulk} := CO3_{ap7}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := 917 \cdot OH_{data}$$

$$CO3_{i_guess} := 8 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 0.211 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 134 \cdot \text{ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{ap7}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 135.802 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.365 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 3.309 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 1.65 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.655 \times 10^4 \frac{\text{mole}}{\text{yr}}$$



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$$\frac{OH_{dep}}{2} = 1.655 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$F_{ap7} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{ap7} = 0.623$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{ap7})$$

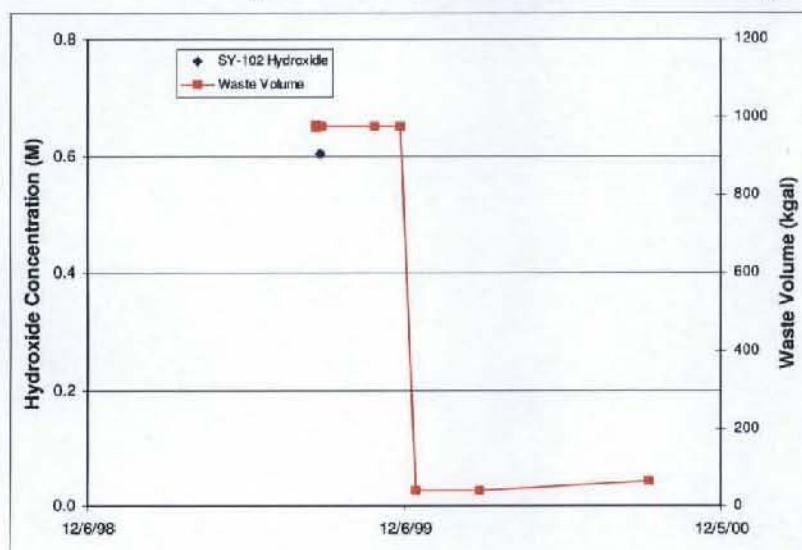
$$C_{co2} = 154.663 \text{ ppm}$$

$$CO2_{ap7} := C_{co2}$$

$$OH_{dep_{ap7}} := OH_{dep}$$

$$OH_{hobbs_{ap7}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

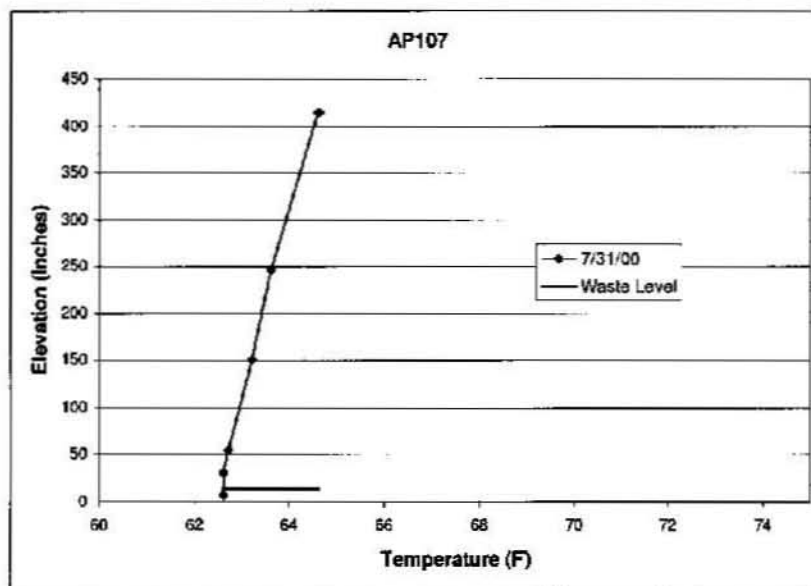
Figure 5-87. AP-107 Waste Volume and Hydroxide Data.



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Figure 5-88. AP-107 7/31/00 Waste Temperature Profile.

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5.25 TANK AP-108

$$Q_{ap8} := Q_{vent4}$$

$$Q_{ap8} = 111 \text{ cfm}$$

$$T_{sup_ap8} := 62\text{F}$$

$$\Delta T_{up8} := .01\text{F}$$

$$V_{saltcake} := 0\text{kgal}$$

$$z_{saltcake} := \frac{V_{saltcake}}{A_{tank}}$$

$$z_{saltcake} = 0 \text{ in}$$

$$V_{sup_ap8} := 33\text{kgal} - V_{saltcake}$$

$$\text{OH}_{data} := 0.89\text{-M}$$

$$\Delta T_{liq} := 0\text{F}$$

$$\text{CO3}_{ap8} := \frac{20000 \frac{\text{mole}}{\text{yr}} \cdot 15\text{yr}}{V_{sup_ap8}}$$

$$\text{CO3}_{ap8} = 2.402 \text{ M}$$

$$D_{liq} = 4 \text{ in}$$



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$$Q := Q_{ap8}$$

$$T_{sup} := T_{sup_ap8}$$

$$CO3_{bulk} := CO3_{ap8}$$

Step 1 - Calculate the Liquid Side Mass Transfer Rates

$$OH_{i_guess} := .945 \cdot OH_{data}$$

$$CO3_{i_guess} := 1.1 \cdot CO3_{bulk}$$

$$CO3_{i_guess} = 2.642 \text{ M}$$

$$OH_{liq_mass_transfer} := \omega_{OH_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess})$$

$$CO3_{mass_transfer} := \omega_{CO3}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, CO3_{bulk}, CO3_{i_guess})$$

$$CO2_{mass_transfer_liq} := \omega_{CO2_liq}(\Delta T_{liq}, T_{sup}, D_{liq}, A_{tank}, OH_{data}, OH_{i_guess}, CO3_{bulk}, CO3_{i_guess})$$

Step 2 - Calculate the Vapor Side OH Depletion Rate

The OH depletion rate based upon the CO2 mass transfer rate is calculated.

$$x_{co2_bulk_guess} := 134 \cdot \text{ppm}$$

$$OH_{dep} := \omega_{OH_air}(\Delta T_{ap8}, T_{sup}, D_{tank}, A_{tank}, OH_{i_guess}, CO3_{i_guess}, x_{co2_bulk_guess})$$

Iterate on the bulk air CO2 concentration guess until it agrees with the calculated concentration.

$$x_{co2_bulk_calc} := x_{bulk} \left(Q, \frac{OH_{dep}}{2} \right)$$

$$x_{co2_bulk_calc} = 133.36 \text{ ppm}$$

Step 3 - Compare the OH Depletion Rate and Liquid OH Mass Transfer Rate

The OH depletion rate based upon the CO2 absorption rate from air is compared to the OH mass transfer rate on the liquid side.

$$OH_{liq_mass_transfer} = 3.307 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

The rate at which OH is depleted in the bulk liquid is

$$OH_{dep_bulk} := 2 \cdot CO2_{mass_transfer_liq}$$

The rate that OH is depleted at the surface is

$$OH_{dep_surface} := OH_{dep} - OH_{dep_bulk}$$

The OH surface depletion rate must be equal to the rate of mass transfer to the surface

$$OH_{dep_surface} = 3.345 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

Step 4 - Compare the OH Depletion Rate to the CO3 Mass Transfer Rate

The CO3 mass transfer rate should be half the surface OH Depletion rate.

$$CO3_{mass_transfer} = 2.143 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$\frac{OH_{dep_surface}}{2} = 1.673 \times 10^4 \frac{\text{mole}}{\text{yr}}$$



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$$\frac{OH_{dep}}{2} = 1.673 \times 10^4 \frac{\text{mole}}{\text{yr}}$$

$$F_{ap8} := \frac{\frac{OH_{dep}}{2}}{x_{co2_amb} \cdot C_{air} \cdot Q}$$

$$F_{ap8} = 0.63$$

$$C_{co2} := x_{co2_pnnl} \cdot (1 - F_{ap8})$$

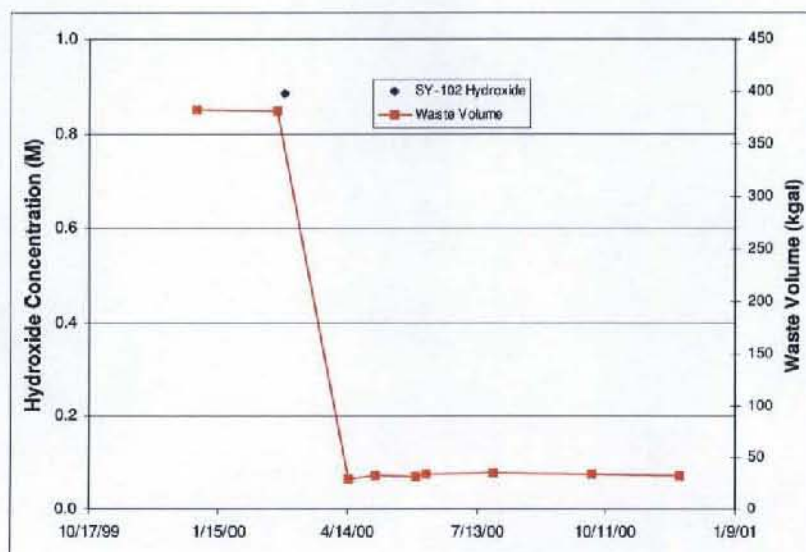
$$C_{co2} = 151.883 \text{ ppm}$$

$$CO2_{ap8} := C_{co2}$$

$$OH_{dep_{ap8}} := OH_{dep}$$

$$OH_{hobbs_{ap8}} := 2x_{co2_amb} \cdot C_{air} \cdot Q \cdot F_{hobbs}(OH_{data})$$

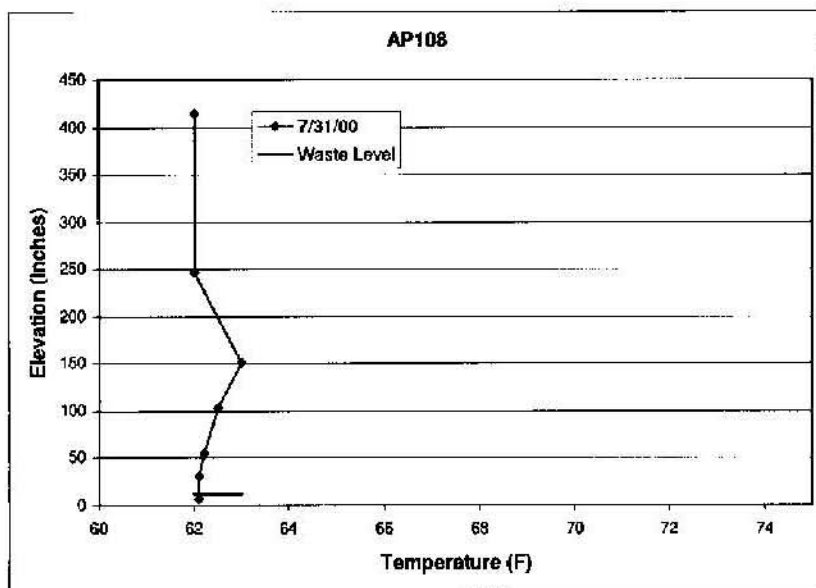
Figure 5-89. AP-108 Waste Volume and Hydroxide Data.



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Figure 5-90. AP-108 7/31/00 Waste Temperature Profile.



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$$Q_{ap} := Q_{ap1} + Q_{ap2} + Q_{ap3} + Q_{ap4} + Q_{ap5} + Q_{ap6} + Q_{ap7} + Q_{ap8}$$

$$i_{data} := 49$$

$$OH_{depcalc, i_{data}} := OH_{depap1} + OH_{depap2} + OH_{depap3} + OH_{depap4} + OH_{depap5} + OH_{depap6} + OH_{depap7} + OH_{depap8}$$

$$OH_{depcalc, i_{data}} = 2.648 \times 10^5 \frac{\text{mol}}{\text{yr}}$$

$$OH_{dephobbs, i_{data}} := OH_{hobbsap1} + OH_{hobbsap2} + OH_{hobbsap3} + OH_{hobbsap4} + OH_{depap5} + OH_{depap6} + OH_{depap7} + OH_{depap8}$$

$$CO2_{data} := 175 \text{ ppm}$$

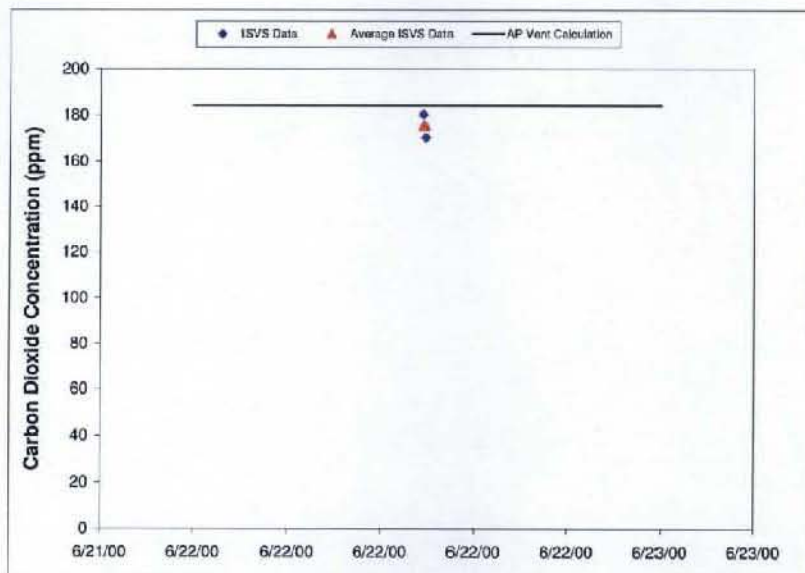
$$CO2_{apcalc} := \frac{CO2_{ap1} + CO2_{ap2} + CO2_{ap3} + CO2_{ap4} + CO2_{ap5} + CO2_{ap6} + CO2_{ap7} + CO2_{ap8}}{8}$$

$$CO2_{apcalc} = 154.578 \text{ ppm}$$

$$OH_{depdata, i_{data}} := \left(1 - \frac{CO2_{data}}{x_{co2_pnnl}} \right) \cdot x_{co2_amb} \cdot C_{air} \cdot Q_{ap} \cdot 2$$

$$OH_{depdata, i_{data}} = 2.437 \times 10^5 \frac{\text{mol}}{\text{yr}}$$

Figure 5-91. AP-Farm Carbon Dioxide Data.



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 $i_{plot} := 1..49$ $OH_{depdata, i_{plot}} =$

$2.058 \cdot 10^4$	$\frac{mol}{yr}$
$4.423 \cdot 10^4$	
$1.194 \cdot 10^5$	
$9.168 \cdot 10^4$	
$1.126 \cdot 10^5$	
$1.052 \cdot 10^5$	
$9.984 \cdot 10^4$	
$1.026 \cdot 10^5$	
$1.236 \cdot 10^5$	
$1.277 \cdot 10^5$	
$1.964 \cdot 10^4$	
$6.319 \cdot 10^4$	
$5.314 \cdot 10^4$	
$2.178 \cdot 10^4$	
$4.009 \cdot 10^4$	
$2.444 \cdot 10^3$	

 $OH_{depcalc, i_{plot}} =$

43.528	$\frac{mol}{yr}$
$3.619 \cdot 10^4$	
$7.869 \cdot 10^4$	
$1.002 \cdot 10^5$	
$1.203 \cdot 10^5$	
$1.069 \cdot 10^5$	
$9.971 \cdot 10^4$	
$1.004 \cdot 10^5$	
$1.142 \cdot 10^5$	
$1.251 \cdot 10^5$	
$1.059 \cdot 10^4$	
$1.114 \cdot 10^4$	
$3.322 \cdot 10^4$	
$3.322 \cdot 10^4$	
$4.645 \cdot 10^4$	
$1.84 \cdot 10^4$	

 $OH_{dephobbs, i_{plot}} =$

$1.667 \cdot 10^4$	$\frac{mole}{yr}$
$5.991 \cdot 10^4$	
$1.224 \cdot 10^5$	
$8.171 \cdot 10^4$	
$1.086 \cdot 10^5$	
$1.016 \cdot 10^5$	
$9.259 \cdot 10^4$	
$9.399 \cdot 10^4$	
$1.201 \cdot 10^5$	
$1.467 \cdot 10^5$	
$5.304 \cdot 10^4$	
$5.277 \cdot 10^4$	
$4.268 \cdot 10^4$	
$3.692 \cdot 10^4$	
$4.822 \cdot 10^4$	
$4.304 \cdot 10^4$	

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APPENDIX C

KELLY CAROTHERS EMAIL

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Donald Ogden

From: "Ogden, Donald M" <Donald M Ogden@RL.gov>
To: <dmogden@icehouse.net>
Sent: Monday, November 14, 2005 8:07 AM
Subject: FW: Core 317, Segment 18 DL evaluation

-----Original Message-----

From: Carothers, Kelly G
Sent: Wednesday, November 09, 2005 7:45 AM
To: Ogden, Donald M
Subject: RE: Core 317, Segment 18 DL evaluation

Don,

The reference with the data is letter FH-0302630, "Report on the Evaluation of Potentiometric Titrations to Determine Hydroxide." The section on the carbon dioxide absorption effect on hydroxide starts on page 25. If you have access to RMIS, you can view the report through that database; otherwise I can fax you the 3 pages of the report with the discussion.

The beakers used in the tests were 15-20 mL scintillation vials with 10 mL of 0.01 M hydroxide solution. The internal diameter of these vials is 1 inch. The neck is narrower, but the solution would be at the 1 inch diameter region.

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APPENDIX D

EQUILIBRIUM CONSTANT

1. INTRODUCTION.

The purpose of this notebook is to define the equilibrium constants for the reaction of carbon dioxide with the OH^- ion.

2. BASIC EQUATIONS

The reaction of concern is:



and



The problem is that we have the equilibrium constant for the second equation (Kotz, Treichel 1999, Ref 4) but not the first equation. We do have some papers from Wikipedia that gives the equilibrium constants for the formation of Carbonic acid due to the reaction of CO_2 with H_2O and then the decomposition of Carbonic acid into HCO_3^- and HCO_3^- into CO_3^{2-} . The Wikipedia information is attached. Thus we have:



where:

$$K_h := 1.70 \times 10^{-3} \quad (2.4)$$

at 25°C .



where:

$$K_{a1} := 2.5 \times 10^{-4} \quad (2.6)$$

at 25°C. This second equilibrium coefficient is similar to the value given in [Ref. 1, p489], $1.3\text{e-}4$, for this reaction.

The dissociation of the bicarbonate ion into the carbonate ion is:



where:

$$K_{a2} := 5.61 \times 10^{-11} \quad (2.8)$$

at 25°C. This is similar to the equilibrium constant given in [Ref. 1, p.489], $4.8\text{e-}11$, for this reaction.

These reactions, with their associated equilibrium coefficients can be converted into the equations for the reaction of CO_2 with the OH^- ion to form HCO_3^- and the reaction of HCO_3^- with the OH^- ion to form CO_3^{2-} by substituting the ions of water in for the H^+ ions and for water in the above equations and using the equilibrium constant for water in the appropriate places.

The equilibrium equation for water is:



where, [Ref. 1],

$$K_w := 1.2 \times 10^{-14} \quad (2.10)$$

at 25°C.

Equations 2.3 and 2.5 can be combined to obtain the combined acidic reaction of CO_2 with water to form the bicarbonate ion.



where

$$K_{1h} := K_h \cdot K_{a1} = \boxed{4.25 \times 10^{-07}} \quad (2.12)$$

The value for this equilibrium constant is nearly equal to that given in [Ref. 1, p.489], $4.2\text{e-}7$.

Substituting Equation 2.9 into this equation gives the alkaline reaction of CO_2 with water to form the bicarbonate ion.



canceling the hydrogen ions out on each side of the equation gives:



where:

$$K_1 := \frac{K_h \cdot K_{a1}}{K_w} = \boxed{3.542 \times 10^{+07}} \quad (2.15)$$

Adding OH^- to each side of Equation 2.7 gives:



Combining with Equation 2.9 gives:



where:

$$K_2 := \frac{K_{a2}}{K_w} = \boxed{4675} \quad (2.19)$$

This value of the reaction constant is nearly identical to that given in Ref 4. Therefore, this methodology appears to give a referenceable value for the reaction constant for Equation 2.12.

To verify that this is so, we will use the activity coefficients that Rob Bratton gave me to determine the equilibrium coefficient for equilibrium reaction 2.14 and 2.18.

The equilibrium constants are given by:

$$K_{1B} = \frac{[\text{HCO}_3^-]}{[\text{CO}_2][\text{OH}^-]} \quad (2.20)$$

and

$$K_{2B} = \frac{[\text{CO}_3^{2-}]}{[\text{HCO}_3^-][\text{OH}^-]} \quad (2.21)$$

where the items in brackets are the activities for the species whose name appears inside of the brackets. From the data for $T=25^\circ\text{C}$,

$$K_{1B} := \frac{[1.2166 \times 10^{-4}]}{[3.2718 \times 10^{-2}] \cdot [8.3227 \times 10^{-11}]} = \boxed{4.468 \times 10^{+07}} \quad (2.22)$$

and

$$K_{2B} := \frac{[4.6919 \times 10^{-11}]}{[1.2166 \times 10^{-4}] \cdot [8.3227 \times 10^{-11}]} = \boxed{4634} \quad (2.23)$$

We now have a referenceable basis upon which to state the

value of the equilibrium constant for the two reactions. The equilibrium constants obtained via the three sources are given in Table 2.1.

3. REFERENCES

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