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Title/Desc:
HEAT REMOVAL CHARACTERISTICS OF WASTE STORAGE

Pages: 53

COMPLETE

ENGINEERING CHANGE NOTICE

Page 1 of ~~X~~ 2 [illegible]

1. ECN 165783

Proj. ECN

2. ECN Category (mark one) Supplemental [] Direct Revision [X] Change ECN [] Temporary [] Standby [] Supersedure [] Cancel/Void []	3. Originator's Name, Organization, MSIN, and Telephone No. GA Chaffee, SA&NE, S7-71, 372-1170	3a. USQ Required? [] Yes [X] No	4. Date 11/15/95
	5. Project Title/No./Work Order No. Tank Farms Hazard and Accident Analysis: Potential for Releases and Required Mitigation and Prevention	6. Bldg./Sys./Fac. No. Tank Farms	7. Approval Designator SQ
	8. Document Numbers Changed by this ECN (includes sheet no. and rev.) WHC-SD-WM-SARR-010, Rev 0	9. Related ECN No(s).	10. Related PO No.

11a. Modification Work [] Yes (fill out Blk. 11b) [X] No (NA Blks. 11b, 11c, 11d)	11b. Work Package No. NA	11c. Modification Work Complete Cog. Engineer Signature & Date	11d. Restored to Original Condition (Temp. or Standby ECN only) Cog. Engineer Signature & Date

12. Description of Change

This report describes and summarizes the results of analyses that examine the relationship between tank heat load and maximum waste temperatures. The passive cooling response of the tanks is examined, and loss of active cooling in ventilated tanks is investigated. This information is utilized in accident scenario liklihood and consequence analysis for the Tank Farm Hazard and Accident Analysis: Potential for Releases and Required Mitigation and Prevention (WHC-SD-WM-SARR-065).

13a. Justification (mark one)

Criteria Change	[X]	Design Improvement	[]	Environmental	[]	Facility Deactivation	[]
As-Found	[]	Facilitate Const	[]	Const. Error/Omission	[]	Design Error/Omission	[]

13b. Justification Details

This revision is being made to be consistent with the technical work performed and reported in WHC-SD-WM-SAR-065, Rev. 0.

14. Distribution (include name, MSIN, and no. of copies)

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ENGINEERING CHANGE NOTICE	Page 2 of 2	1. ECN (use no. from pg. 1) 165783

15. Design Verification Required
☐ Yes
☒ No

16. Cost Impact

	ENGINEERING			CONSTRUCTION	
Additional	☐	$	Additional	☐	$
Savings	☐	$	Savings	☐	$

17. Schedule Impact (days)
Improvement ☐
Delay ☐

18. Change Impact Review: Indicate the related documents (other than the engineering documents identified on Side 1) that will be affected by the change described in Block 12. Enter the affected document number in Block 19.

SDD/DD ☐
Functional Design Criteria ☐
Operating Specification ☐
Criticality Specification ☐
Conceptual Design Report ☐
Equipment Spec. ☐
Const. Spec. ☐
Procurement Spec. ☐
Vendor Information ☐
OM Manual ☐
FSAR/SAR/ISB ☒
Safety Equipment List ☐
Radiation Work Permit ☐
Environmental Impact Statement ☐
Environmental Report ☐
Environmental Permit ☐

Seismic/Stress Analysis ☐
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Interface Control Drawing ☐
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ICRS Procedure ☐
Process Control Manual/Plan ☐
Process Flow Chart ☐
Purchase Requisition ☐
Tickler File ☐
☐
☐

19. Other Affected Documents: (NOTE: Documents listed below will not be revised by this ECN.) Signatures below indicate that the signing organization has been notified of other affected documents listed below.

Document Number/Revision	Document Number/Revision	Document Number Revision

20. Approvals

	Signature	Date		Signature	Date
OPERATIONS AND ENGINEERING			**ARCHITECT-ENGINEER**		
Cog. Eng.	M. Kummerer Maryanne Kummerer	11/14/95	PE		
Cog. Mgr.	D. S. Leach DS Leach	11/14/95	QA		
QA	SEE SAFETY SIGNATURE	11/16/95	Safety		
Safety	M.N. ISLAM	11/16/95	Design		
Environ.			Environ.		
Other			Other		

DEPARTMENT OF ENERGY

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ADDITIONAL

RELEASE AUTHORIZATION

Document Number: WHC-SD-WM-SARR-010, REV 1

Document Title: Heat Removal Characteristics of Waste Storage Tanks

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SUPPORTING DOCUMENT

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Heat Removal Characteristics of Waste Storage Tanks

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7. Abstract

A topical report that examines the relationship between tank heat load and maximum waste temperatures. The passive cooling response of the tanks is examined, and loss of active cooling in ventilated tanks is investigated.

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HEAT REMOVAL CHARACTERISTICS OF WASTE STORAGE TANKS

WHC-SD-WM-SARR-010 REV 1

October 1995

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HEAT REMOVAL CHARACTERISTICS OF WASTE STORAGE TANKS

1.0 SUMMARY AND CONCLUSIONS

1.1 SUMMARY

This report describes and summarizes the results of analyses that examine the thermal response of the Hanford Site waste storage tanks. Maximum allowable heat loads were estimated for two temperature limits for tanks without active cooling.

The first limit is Safety Limit 2.2, "Single Shell Tank (SST) Maximum Waste Temperature" from the SST Interim Operational Safety Requirements (IOSR) (Dougherty 1994), specified as 177 °C (350 °F) for all SSTs. The second limit is the criterion to ensure tanks containing reactive chemicals (ferrocyanide and organic compounds) remain moist and, therefore are maintained in a "conditionally safe" state (Postma et al. 1994; Babad and Turner 1993). The maximum allowable temperature to preclude moisture loss is 90 °C (194 °F).

Heat loads for the passively ventilated SSTs, calculated from steady-state vapor space temperatures, were compared with the limits to verify that a safety margin exists for all the tanks. Conduction heat losses from tanks on active ventilation in the SX Tank Farm were also calculated to provide a lower bound for the heat load in those tanks. Estimates of heat loss from ventilation for those tanks were calculated using ventilation flow and vapor space condition measurements. Heat loads for ventilated tanks C-105 and C-106 were taken from previous work (Bander 1993a, 1993b).

The response of actively ventilated SSTs to loss of cooling was analyzed. A bounding case for each of the temperature limits was chosen, and the time it would take for waste temperatures to reach the limit was estimated. For the 177 °C (350 °F) limit, the temperature rise for a tank with 29,300 W (100,000 BTU/h) heat load was examined. The result was compared with that observed in tank C-106 when the ventilation system was off during a 5-month period. For the reactive chemical temperature limit, conditions corresponding to tank SX-103 were modeled.

Finally, the effect of losing ventilation cooling on the double-shell tanks (DST) in the AN, AP, AW and SY Tank Farms was examined. Calculations of adiabatic heating were used to estimate the time it would take the liquid waste to achieve boiling temperatures. The potential for radioactive releases from the tank because of boiling waste was considered.

1.2 CONCLUSIONS

In a tank with passive breathing only, the waste temperature will not rise above 177 °C (350 °F) if the heat load is less than 11,700 W (40,000 BTU/h). Passively ventilated tanks with reactive waste require a heat load less than 5,860 W (20,000 BTU/h) to ensure a safety margin to the 90 °C (194 °F) temperature criterion without active cooling.

All of the unventilated tanks, with one exception, have estimated heat loads less than 5,860 W (20,000 BTU/h) and waste temperatures below 71 °C (160 °F). This provides a sizable safety margin against exceeding the structural safety limit. Tank A-104 has a heat load estimated at 15,200 W (52,000 BTU/h) and a waste temperature of 90 °C (194 °F). It has not been actively cooled for over 2 years, yet the temperature remains well below the limit for structural integrity. It was concluded that, partly because of the shallow depth of waste in the tank, passive heat removal from the tank is sufficient to maintain temperature within safe limits.

The passively ventilated tanks that are currently on the ferrocyanide and organic watch lists have estimated heat loads less than 5,860 W (20,000 BTU/h) and all have waste temperatures below 70 °C (155 °F). Again, the safety margins are adequate for these tanks.

Two organic tanks, SX-106 and SX-103, have temperatures of 43 and 79 °C (110 and 174 °F), respectively, under ventilation. The total heat load in tank SX-106 was estimated to be 7,900 W (27,000 BTU/h). The total heat load in tank SX-103 was estimated to be 8,200 W (28,000 BTU/h). It was estimated that if active cooling were lost on tank SX-103, it would take about 6 months for waste temperatures to rise to the 90 °C (194 °F) limit.

The SST with the highest heat load, tank C-106, was chosen as the bounding case to examine temperature response to loss of active cooling. The minimum time to reach the temperature limit for structural integrity was estimated to be 240 days.

The minimum time to achieve boiling temperatures in the AN, AP, AW and SY Tank Farm DSTs, assuming adiabatic heating, was calculated to be on the order of 2 years. Further analysis is recommended to further quantify the risk of releases from waste boiling in DSTs.

The analysis results reported here are based on best available data from the tanks. In cases where reliable data were lacking, conservative parameters were used. As more tank data become available through improved waste characterization and/or more refined analysis, tank heat load estimates may be revised.

2.0 OBJECTIVES AND SCOPE

The purpose of this report is to examine the thermal response characteristics of the waste storage tanks in the 200 Areas tank farms. A knowledge of the expected thermal response of the tanks is necessary for understanding the conditions under which various temperature limits might be exceeded.

IOSRs impose waste temperature limits for both the SSTs and DSTs. These limits are based on protecting the ability of the tank materials (concrete and structural steel) to perform their intended functions.

It is also desirable to maintain the temperature of certain reactive waste below the boiling temperature of the tank liquids so that they will not dry out. The presence of water in ferrocyanide and organic waste reduces or removes their potential to sustain a propagating reaction. Therefore, the criterion for placing a tank that is on the ferrocyanide or high organic watch list in the "conditionally safe" category is that the temperature must not rise above 90 °C (194 °F).

Maintaining the DST below boiling temperatures may also be warranted. In case of ventilation failure, the tank pressure would rapidly equalize with the atmosphere. If waste temperatures reach boiling, and remain there for a long time, radioactive materials could be entrained in the vapor space air and be released to the environment through unfiltered leak paths.

2.1 OBJECTIVES

The analyses for the SSTs discussed here were directed toward three related objectives:

(1) Estimating the maximum heat load a tank can hold without exceeding each of the temperature limits, if no active cooling is provided.

(2) Estimating, as far as possible, the heat loads the SSTs now contain, for comparison with the allowable heat loads.

(3) Estimating cooling requirements and the response to loss of cooling for the tanks that have estimated heat loads exceeding the estimated allowable.

The primary source of tank heat is the ongoing radioactive decay in the waste. The temperatures achieved in the tank materials and in the waste are related to the magnitude and distribution of the heat-generating components in the waste. Therefore, temperature is primarily controlled by controlling the heat-generating capability of the waste.

For SSTs, because further waste additions are not allowed, the present radioactive heat loads are higher than they will be in the future. Liquid waste may be removed in future from tanks that remain to be interim stabilized. This will have the effect of decreasing their heat loads. Therefore, assessment of the need for active cooling of the SSTs was based on the calculation of their current heat loads from the measured temperatures in the vapor space. Where temperature control is required, the degree of necessary cooling is estimated.

Because DSTs are still in service, future waste transfers into them are possible. Therefore, the analysis of DSTs focuses on how quickly the temperature would rise if cooling were lost and the minimum time that would be required for cooling to be restored.

2.2 SCOPE

This study provides estimates of the steady-state heat loads for the SSTs that do not have active ventilation. This included tanks in the A, AX, B, BX, BY, C, S, SX, T, TX, TY, and U Tank Farms. Some tanks do not have functioning thermocouples, and no recent temperature data were found. Historical information provided some data for a few of these tanks. For the others, heat loads were not calculated. No temperatures recorded before 1980, when the tanks were isolated, were used. Heat loads were also estimated for the 55,000-gal (approximately 200,000-L) tanks in the B, C, T, and U Tank Farms (200 Series).

SSTs that are actively ventilated include C-105, C-106, SX-101 through SX-113, and SX-115 (Hanlon 1994). Tanks A-104, A-105, and A-106 were actively ventilated in the recent past, but the ventilator has not been operational for at least 2 years. Therefore, all of the A Farm tanks are treated as passively ventilated tanks.

The temperatures in the A Farm tanks may also be influenced by the high temperatures in the soil under tank A-105 and, therefore the temperature heat load correlation may not be entirely valid for those tanks. Further investigation of these effects between the A Farm tanks may be warranted.

Adiabatic temperature rise in response to loss of ventilation in the AN, AW, AP and SY DSTs was studied. The analysis estimated the minimum time to achieve boiling temperature under current tank conditions. In addition, the minimum time to boiling was estimated assuming future waste additions to the maximum allowed waste level. The AY and AZ Farm tanks (aging waste tanks) are not within the scope of this report.

3.0 BACKGROUND

The 149 single-shell waste storage tanks on the Hanford Site were built between 1943 and 1964. They received waste streams from various processes until 1980, when they were taken out of service. Since that time, waste transfers into the SSTs have been prohibited. Liquid waste has been removed to reduce the potential for leaks into the soil.

The 28 DSTs were constructed between 1968 and 1986, and are still in service. Transfers into the DSTs are controlled to ensure that mixing of the new waste with waste already in the tank will not produce consequences outside established limits, e.g., pH, potential for chemical reactions, waste temperature.

Waste temperatures in all of the tanks are limited by administrative control. The limits are set to maintain the tank materials at temperatures that will not compromise their structural or containment function. The maximum waste temperature allowed by administrative control for SSTs is 149 °C (300 °F) (Dougherty 1994). For DSTs, the maximum waste temperature allowed is 177 °C (350 °F) for tanks in the AN and AW Tank Farms, 99 °C (210 °F) for tanks in the AP Tank Farm, and 121 °C (250 °F) for tanks in the SY Tank Farm (Heubach 1994).

Additional restrictions on maximum waste temperatures have recently been established for tanks that contain significant amounts of reactive chemicals. These are the tanks on the ferrocyanide and organic watch lists. The watch lists have been in existence since 1991. A recent re-evaluation resulted in the addition of ten tanks to the organic watch list (Payne 1994). Discussion of the organic watch list in this report includes those 10 tanks.

Documentation is now in place for establishing criteria for maintaining these tanks in a conditionally safe state (Postma et al. 1994; Babad and Turner 1993). One of these criteria is a waste temperature below 90 °C (194 °F). This will preclude losing moisture by boiling off the free liquid.

In the tanks that have high enough heat load to reach the limit for material integrity, and in tanks that are on the watch lists because of reactive chemical content, temperatures are monitored to ensure a safety margin continues to exist. The estimated heat generation rate of the waste in the tank identifies which tanks have the potential for reaching either limit if there is no active cooling system.

3.1 SINGLE-SHELL TANKS

Traditionally, heat generation rates of waste in the Hanford Site tanks have been calculated from measured or estimated radioactive inventories. A number of unknown factors contribute to large uncertainties in the inventories of the SSTs. The size and radionuclide composition of transfers between tanks over the years is only roughly known.

Where data from tank samples are available, uncertainties arise from several factors. It may be unknown to what degree the sample location is representative of the tank contents. Incomplete sample recovery and the analysis method used may also introduce uncertainties. Characterizing these uncertainties is problematic, particularly for older sample data.

There is an ongoing effort to improve sampling and analysis methods and to characterize the waste in all the SSTs. This is necessarily a slow process and it will be some time before reliable data for all tanks are available.

3.2 DOUBLE-SHELL TANKS

Waste transfers to DSTs have been more recent. The composition of waste additions is controlled by administrative procedures. Before waste is added to a tank its radionuclide content is characterized. Therefore, the heat loads of the DSTs are more accurately known.

Moreover, all DSTs are actively ventilated to control tank pressure and flammable gas buildup. Waste temperatures, as well as temperatures in the concrete structure, are monitored routinely.

4.0 ESTIMATES OF CURRENT HEAT LOADS

Radioactive decay is the main contributor to heat generation in the waste tanks; exothermic chemical reactions may also contribute some heat. There are undetermined uncertainties in tank heat load estimates that have been based on radionuclide inventories of the tank contents. This is because transfer records and old sample data often do not give an unambiguous picture of a tank's contents.

Even when new sample data are available, the radionuclide content of the samples may not be representative of the whole waste. Assuming uniform distribution may lead to significant overestimation or underestimation of the heat generation rate in the tank.

Tank heat load estimates may be made using easily obtained and reliable physical data. Tank vapor space temperatures and psychrometric data for ventilation flows, along with atmospheric data, provide the information required to specify the problem.

4.1 HEAT LOADS FOR PASSIVELY VENTILATED TANKS AT STEADY STATE

The current heat loads for SSTs that are not actively ventilated were estimated from the vapor space temperature histories. The calculation of heat loads is based on the assumption that the tanks are essentially at a thermal steady state. The portion of the waste heat rate that is transmitted upward flows from the waste surface into the vapor space. The vapor space air in passively ventilated tanks is generally well mixed thermally. Vapor space temperature profiles for these tanks show nearly uniform temperatures from the waste surface to the tank top. Convective and radiative heat losses from the waste surface contribute significantly to this uniformity (Crowe et al. 1993).

Problems of heat conduction in solids with periodic surface temperature variations arise from the study of fluctuations in temperature of the earth's crust caused by periodic heating by the sun. The periodic oscillations in the atmospheric temperature have been used for determining the thermal conductivity of rocks. Observations of the temperature at points near the surface of the earth have established that the variations of surface temperatures from the "heat by day" to the "cool by night" do not affect points at a depth of more than 0.9 to 1.2 m (3 to 4 ft). However, the yearly changes from "cold of winter" to the "heat of summer" may be observed up to a depth of 18 to 21 m (60 to 70 ft) (Carslaw and Jaeger 1959).

The tanks lie below grade at a distance of approximately 2.4 m (8 ft) (top of tank) to about 15 m (50 ft) (bottom of largest tanks). Therefore, the tank temperatures will be influenced by these seasonal fluctuations. A seasonal variation in the tank vapor space temperatures can be observed. Figure 1 illustrates the harmonic nature of these temperature variations for representative tank BY-104. Figure 2 plots the atmospheric temperature data for the same time period, between January 1990 and January 1993. Both sets of data were fitted with a Fourier series approximation (Crowe et al. 1993).

Figure 1. Temperature Fluctuations in Tank 241-BY-104 Vapor Space.

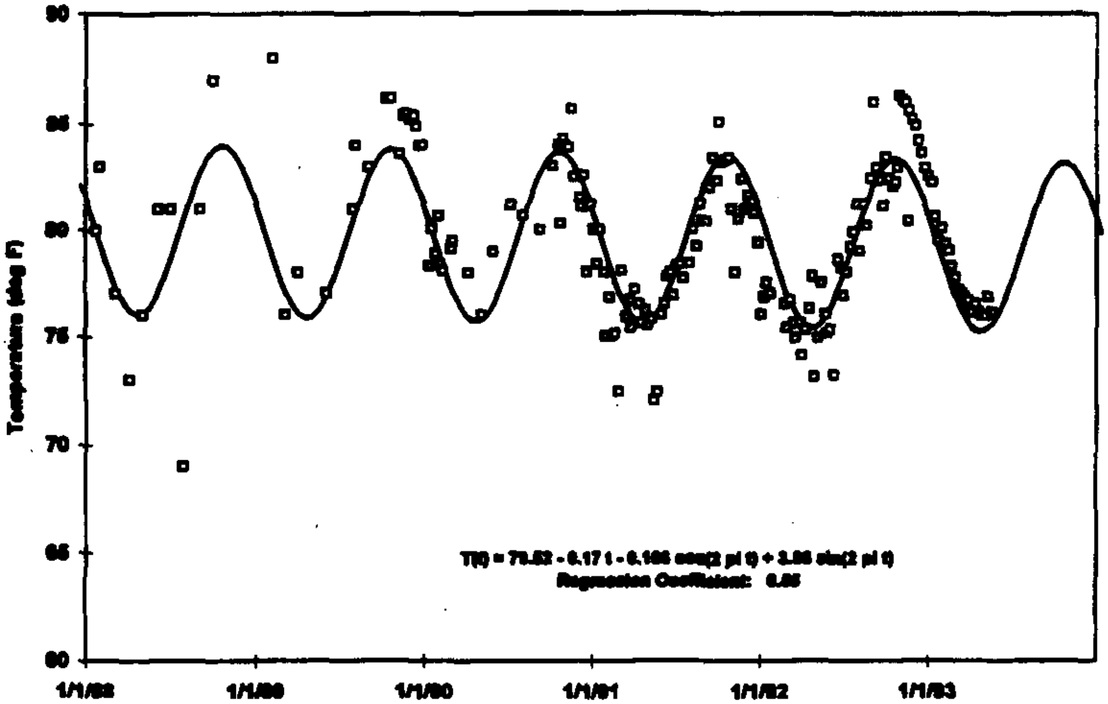
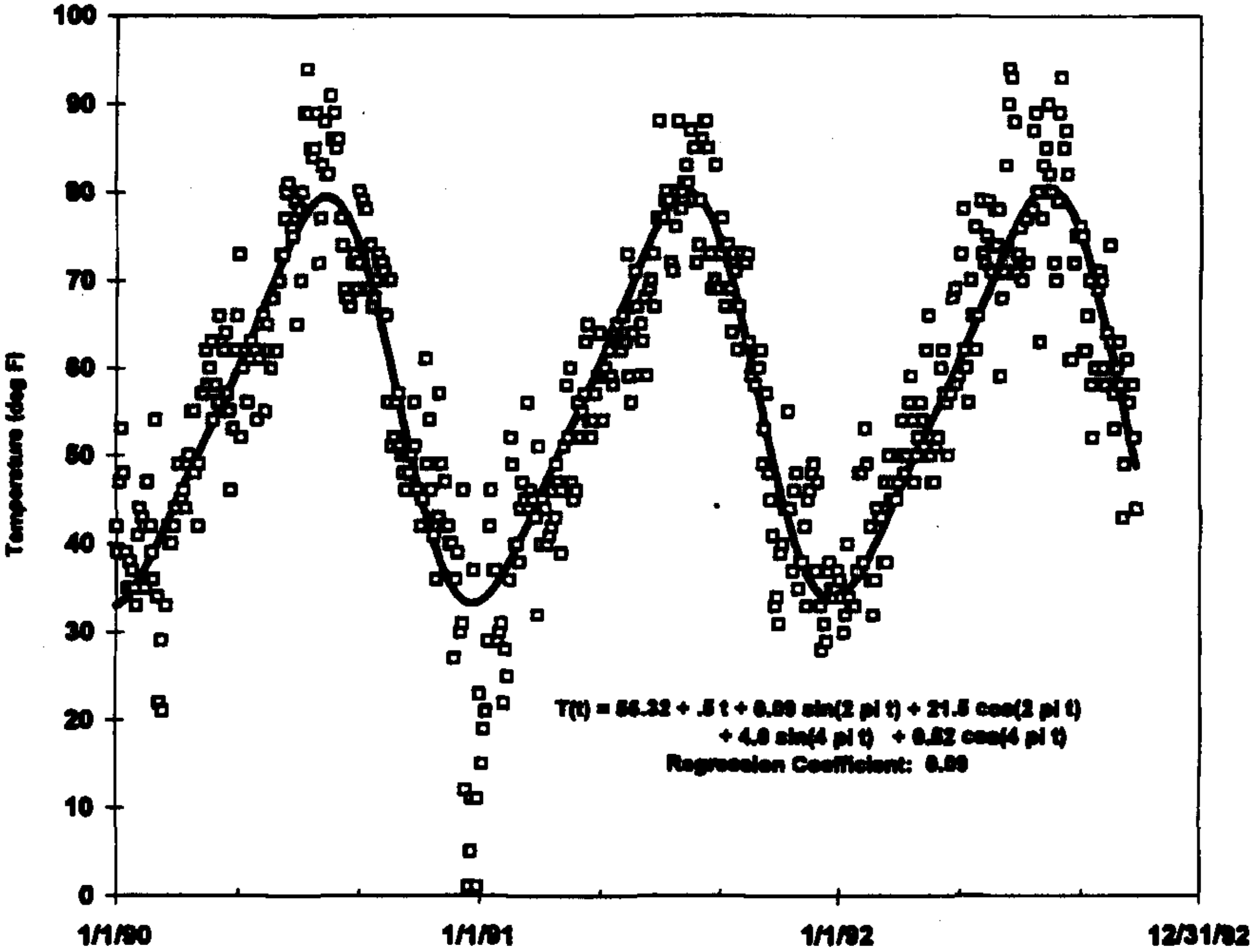


Figure 2. Seasonal Atmospheric Temperature Fluctuations.



The temperature oscillation in tank BY-104 shows a similar period to the atmospheric temperature data. However, the phase of the tank temperatures is shifted by about 90 days with respect to the atmospheric fluctuations. In addition, the amplitude of the temperature swing in the tanks is less than those of the outside air. This effect on phase and amplitude is characteristic and allows full specification of the heat transmission rate through the soil overburden without knowing the thermal properties of the soil. Furthermore, solution of the problem provides a means for estimating the thermal diffusivity of the soil.

Crowe et al. (1993) describe the development of this method as it applies to the waste tanks. The close correlation of the temperature phase shift and amplitude damping parameters for selected tanks provided indication that small ventilation effects from atmospheric breathing and convective exchanges do not significantly alter the validity of the method.

The study further showed that, if the zero of the periodic function fit to the temperature data is taken as an average, good agreement for heat flux rates can be obtained by the much simplified method of a one-dimensional conduction calculation through the soil. The average of the atmospheric temperature data occurred at about April 15, with a value of 13.5 °C (56.3 °F). The average of the tank vapor space data was found to be around July 15 for the tanks examined in the study.

The findings of this study made it possible to make conservative, but realistic, estimates of the heat loads in the passively ventilated SSTs for which vapor space temperature data are available. The method relates the total heat load in the tank to the vapor space temperature and the depth of waste in the tank. Furthermore, the method does not require knowledge of the thermal properties of the tank waste.

$$Q_{total} = C_f \left(T_{vapor\ space} - T_{air}\right) \tag{1}$$

where:

C_f = Conversion factor = $\dfrac{R_0\ k_{soil} \cdot area}{(Z_{tank} - Z_{surface})}$

R_0 = Ratio of total heat load to heat out the top of the tank (function of waste height)

Area = cross sectional area of the tank waste

k_{soil} = thermal conductivity of soil

$(Z_{tank} - Z_{surface})$ = effective depth of soil covering the top of tank

$(T_{vapor\ space} - T_{air})$ = mean temperature difference between vapor space and the ambient air at the surface

The conversion factor, C_f, comes from the recognition that the heat conducted through the top of the tank does not represent the total heat leaving the tank. A portion of the heat generated by the waste is conducted through the bottom and side of the tank. The proportion conducted out the side is a function of the depth of waste in the tank.

Figure 3 (Crowe et al. 1993) illustrates the estimated fraction of the total heat loss from the tank through four areas: the tank top, the tank bottom, the tank side below the waste level, and the tank side above the waste level for 500,000- and 750,000-gal (1,900,000- and 2,800,000-L) tanks. These ratios were used in calculating C_f for the total heat loads for those tanks. Ratios for the 1,000,000- and 55,000-gal (3,800,000- and 200,000,000-L) tanks were similarly calculated but not shown on the graph.

The thermal conductivity of the soil, derived from the analysis of the vapor space temperature fluctuations for five tanks, each in a different tank farm (Crowe et al. 1993), is used in this simplified calculation. It is taken to be 1.04 $W\ m^{-1}\ K^{-1}$ (0.6 $BTU\ h^{-1}\ ft^{-1}\ °F^{-1}$). Because this value derives from the physics of the system observed over a yearly cycle, it provides a rough estimate of the average soil conductivity during the cycle.

This value for soil thermal conductivity is about 20% higher than measured values for soil with 12% water by weight from SX farm samples, and about double the measured value for dry soil (McLaren 1993). Therefore, any uncertainties introduced by using this value will lead to overestimating tank heat loads.

An effective soil depth, to account for the curvature of the tank top, was taken to be 4.0 m (13.2 ft). T_{air} was taken to be 13.8 °C (56.3 °F), the average ambient temperature derived from the Fourier series fit to the atmospheric data. Where available, recorded tank vapor space temperatures for July 1993 were used for $T_{vapor\ space}$. In the cases where weekly temperature readings were available, the average of all the July temperatures was used. In other tanks, only one July temperature was recorded.

For tanks that did not have 1993 data, older records were searched and the most recent July or January data were used. If the latest temperature record found was more than 10 years old (one-third the half-life of the major radionuclide contributors), the heat load calculations were decayed to the present, assuming a 30-year half-life.

In some cases, no January or July data were found, so the average value was interpolated, using the harmonic curve, from the date of the temperature reading. Heat loads could not be calculated for nine passively cooled SSTs because search of the records revealed no temperature data later than 1980 for them.

Tables 1 through 3 list the passively ventilated SSTs with the relevant temperatures and estimated heat loads. Table 4 gives the same data for the 200 Series tanks. Figures 4 through 6 show the relationship of maximum waste temperatures to the calculated heat loads for the tanks by size. The linear fit through the data provides a rough average of the relationship between the waste temperatures and heat loads calculated by this method.

Figure 3. Heat Load Fractions.

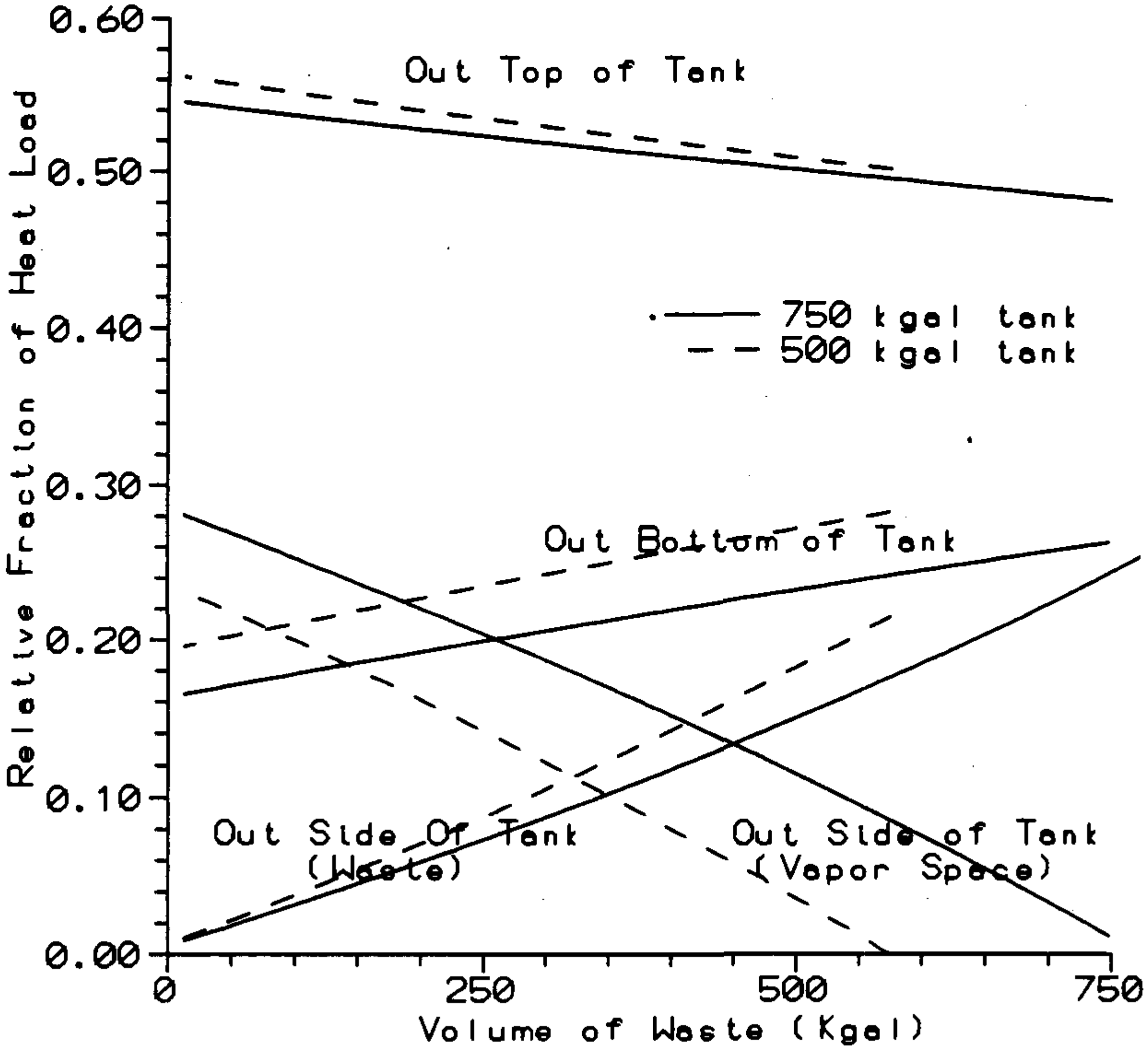


Table 1. Temperatures and Estimated Heat Loads for Passively Ventilated 500,000-Gallon Single-Shell Tanks. (3 sheets)

Tank	Waste level (ft)	Waste volume (Kgal)	Vapor space temperature (°F)	Waste temperature (°F)	Heat load (BTU/h)
B-101	4.0	113	91.7	107.7	12,922
B-102	1.6	32	63.5	62.8	2,583
B-103[a]	2.4	59	61.7	59.8	1,941
B-104	11.9	371	62.8	65.6	2,502
B-105	9.9	306	63.1	66.5	2,583
B-106	4.2	117	61.8	61.7	2,009
B-107	5.6	165	61.9	61.9	2,067
B-108	3.5	94	61.7	61.7	1,963
B-109	4.5	127	61.1	60.9	1,757
B-110	8.1	246	67.8	68.3	4,316
B-111	7.8	237	85.6	85.7	10,976
B-112	1.6	33	63.1	63.2	2,440
BX-101	1.9	42	63.9	64.6	2,733
BX-102[b]	3.4	96	65.4	63.6	3,324
BX-103	2.6	66	77.0	N/A	5,742
BX-104	3.6	99	87.0	N/A	6,208
BX-105	2.2	51	66.1	72.7	3,518
BX-106[b]	2.0	31	63.3	63.7	2,511
BX-107	8.0	345	72.0	N/A	4,615
BX-108	1.4	26	65.4	72.0	3,273
BX-109	6.5	193	74.8	76.7	6,867
BX-110	6.7	198	62.5	67.3	2,304
BX-111	7.6	211	64.8	65.7	3,167
BX-112	5.6	165	64.9	71.2	3,161
C-101	3.3	88	85.2	87.3	10,493
C-102[a]	13.6	423	89.6	N/A	12,952
C-103[a]	7.0	195	105.3	118.6	18,196

Table 1. Temperatures and Estimated Heat Loads for Passively Ventilated 500,000-Gallon Single-Shell Tanks. (3 sheets)

Tank	Waste level (ft)	Waste volume (Kgal)	Vapor space temperature (°F)	Waste temperature (°F)	Heat load (BTU/h)
C-104	9.6	295	86.4	89.5	11,410
C-107	10.8	275	108.7	121.9	19,783
C-108[b]	2.5	66	72.8	71.5	5,963
C-109[b]	2.5	62	75.8	73.5	7,041
C-110	6.7	187	64.9	65.2	3,188
C-111[b]	2.4	57	74.0	74.2	6,384
C-112[b]	3.8	104	77.0	72.8	7,542
T-101	4.7	102	67.8	66.0	4,188
T-102	1.6	32	75.0	N/A	3,843
T-103	1.4	27	59.3	58.8	1,075
T-104	14.1	445	64.6	N/A	3,242
T-105	3.6	98	73.7	N/A	4,988
T-106	1.3	21	59.3	59.1	1,074
T-107[b]	6.1	180	62.8	62.0	2,416
T-108	2.0	44	63.0	N/A	2,198
T-109	2.4	58	62.0	N/A	1,770
T-110[b]	12.1	379	59.4	59.8	1,180
T-111	14.5	458	58.4	59.1	822
T-112	2.7	67	58.8	58.7	904
U-101	1.4	25	67.0	N/A	3,833
U-102	12.0	374	71.1	80.8	5,701
U-103[a,c]	14.8	468	73.1	83.8	6,593
U-104	4.3	122	N/A	N/A	NC
U-105[a,c]	13.3	418	72.7	86.2	6,373
U-106[a]	7.5	226	71.4	76.7	5,629
U-107[a,c]	12.9	406	70.4	74.7	5,475
U-108[c]	14.8	468	73.1	84.3	6,593

Table 1. Temperatures and Estimated Heat Loads for Passively Ventilated 500,000-Gallon Single-Shell Tanks. (3 sheets)

Tank	Waste level (ft)	Waste volume (Kgal)	Vapor space temperature (°F)	Waste temperature (°F)	Heat load (BTU/h)
U-109[c]	14.7	463	71.3	81.8	5,865
U-110	6.3	186	68.4	71.7	4,485
U-111[a]	10.6	329	69.5	75.6	5,038
U-112	2.1	49	61.1	60.8	1,728

Note: To convert from BTU/h to watts, divide by 3.413.

[a] Organic watch list tank.

[b] Ferrocyanide watch list tank.

[c] Flammable gas watch list tank.

N/A = not available.

NC = not calculated.

Table 2. Temperatures and Estimated Heat Loads for 750,000-Gallon Single-Shell Tanks. (3 sheets)

Tank	Waste level (ft)	Waste volume (Kgal)	Vapor space temperature (°F)	Waste temperature (°F)	Heat load (BTU/h)
BY-101	12.0	387	65.8	74.3	3,700
BY-102	11.0	341	76.0	N/A	5,536
BY-103[b]	12.7	400	70.3	81.0	5,500
BY-104[b]	10.9	406	78.5	127.2	8,700
BY-105[b]	15.2	503	78.0	114.3	8,700
BY-106[b]	20.2	642	81.0	128.7	10,100
BY-107[b]	8.6	266	79.3	95.0	8,900
BY-108[b]	7.5	228	80.3	108.3	9,200
BY-109	13.4	423	60.0	N/A	1,036
BY-110[b]	12.5	396	73.8	117.9	6,900
BY-111[b]	14.5	459	70.0	88.2	5,500
BY-112[b]	9.4	291	72.0	82.8	6,100
S-101	13.6	427	91.0	115.0	13,736
S-102[a,c]	17.3	549	76.9	104.3	8,331
S-103	8.1	248	71.2	84.6	5,719
S-104	9.5	294	83.6	103.5	10,563
S-105	14.4	456	65.7	73.0	3,739
S-106	17.1	543	65.9	93.7	3,875
S-107	11.8	368	80.1	106.8	9,327
S-108	18.9	604	67.1	85.8	4,403
S-109	17.8	568	76.0	83.0	7,984
S-110	21.6	390	76.2	115.9	7,828
S-111[a,c]	18.7	596	72.0	88.6	6,393
S-112[c]	19.9	637	67.2	73.0	4,468
TX-101	3.3	87	N/A	N/A	NC
TX-102	4.0	113	N/A	N/A	NC
TX-103	5.4	157	58.0	58.0	642
TX-104	2.6	65	60.0	60.0	1,375

Table 2. Temperatures and Estimated Heat Loads for 750,000-Gallon Single-Shell Tanks. (3 sheets)

Tank	Waste level (ft)	Waste volume (Kgal)	Vapor space temperature (°F)	Waste temperature (°F)	Heat load (BTU/h)
TX-105[a]	19.1	609	72.9	95.0	6,784
TX-106	14.4	453	59.0	59.0	1,073
TX-107	1.7	36	59.0	60.0	998
TX-108	4.7	134	60.0	61.0	1,392
TX-109	12.3	384	62.0	64.0	2,240
TX-110	14.6	462	81.0	N/A	9,835
TX-111	11.8	370	72.0	65.0	6,155
TX-112	20.3	649	80.0	73.0	9,734
TX-113	19.0	607	70.0	64.0	5,588
TX-114	16.8	535	N/A	N/A	NC
TX-115	20.0	640	70.0	65.0	5,619
TX-116	19.7	631	N/A	N/A	NC
TX-117	19.6	626	N/A	N/A	NC
TX-118[a,b]	9.8	347	68.6	74.7	4,789
TY-101[b]	4.28	118	64.7	63.8	3,140
TY-102	2.6	64	63.6	N/A	2,712
TY-103[b]	5.6	162	65.8	68.5	3,607
TY-104[a,b]	2.0	46	64.5	64.4	3,033
TY-105	7.6	231	65.5	76.6	3,521
TY-106	1.1	17	60.1	59.8	1,400

Note: To convert from BTU/h to watts, divide by 3.413.

[a] Organic watch list tank.

[b] Ferrocyanide watch list tank.

[c] Flammable gas watch list tank.

N/A = not available.

NC = not calculated.

Table 3. Temperatures and Estimated Heat Loads for Passively Ventilated 1,000,000-Gallon Single-Shell Tanks.

Tank	Capacity (gal)	Waste height (ft)	Waste volume (Kgal)	Vapor space temperature (°F)	Waste temperature (°F)	Heat load (BTU/h)
A-101[a,b]	1,000,000	28.9	953	98.6	154.0	18,379
A-102	1,000,000	1.2	41	89.9	92.0	12,827
A-103	1,000,000	11.2	370	85.7	117.0	11,786
A-104[c]	1,000,000	0.9	28	193.1	194.0	52,120
A-105[c]	1,000,000	1.2	19	N/A	142.0	50,000[d]
A-106	1,000,000	3.8	125	105.6	137.0	19,061
AX-101[b]	1,000,000	22.7	748	90.1	137.0	14,304
AX-102[a]	1,000,000	1.2	39	75.7	76.0	7,385
AX-103[b]	1,000,000	3.4	112	90.3	115.0	13,101
AX-104	1,000,000	0.2	7	94.2	98.0	14,393
SX-113	1,000,000	1.2	26	74.2	73.0	6,818
SX-115	1,000,000	0.8	12	N/A	N/A	NC

Note: To convert from BTU/h to watts, divide by 3.413.
[a] Organic watch list tank.
[b] Flammable gas watch list tank.
[c] High heat tank.
[d] Hanlon 1994.
N/A = not available.
NC = not calculated.

Table 4. Temperatures and Estimated Heat Loads for 55,000-Gallon Single-Shell Tanks.

Tank	Waste level (ft)	Waste volume (Kgal)	Vapor space temperature (°F)	Heat load (BTU/h)
B-201	12.58	29	58.9	185
B-202	11.73	27	59.1	198
B-203	21.93	51	58.3	146
B-204	21.51	50	58.5	161
C-201	1.1	2	62.0	390
C-202	0.67	1	61.2	335
C-203	2.38	5	59.4	213
C-204	1.52	3	NA	NC
T-201	12.58	29	56.5	14
T-202	9.18	21	56.8	35
T-203	15.13	35	75.5	1,375
T-204	16.41	38	57	50
U-201	2.38	5	NA	NC
U-202	2.38	5	58.8	172
U-203[a]	1.52	3	63	500
U-204[a]	1.52	3	79.9	1,616

Note: To convert from BTU/h to watts, divide by 3.413.
[a]Organic watch list tank.
N/A = not available.
NC = not calculated.

Figure 4. Waste Temperature vs Heat Load in 500,000-Gallon Single-Shell Tanks.

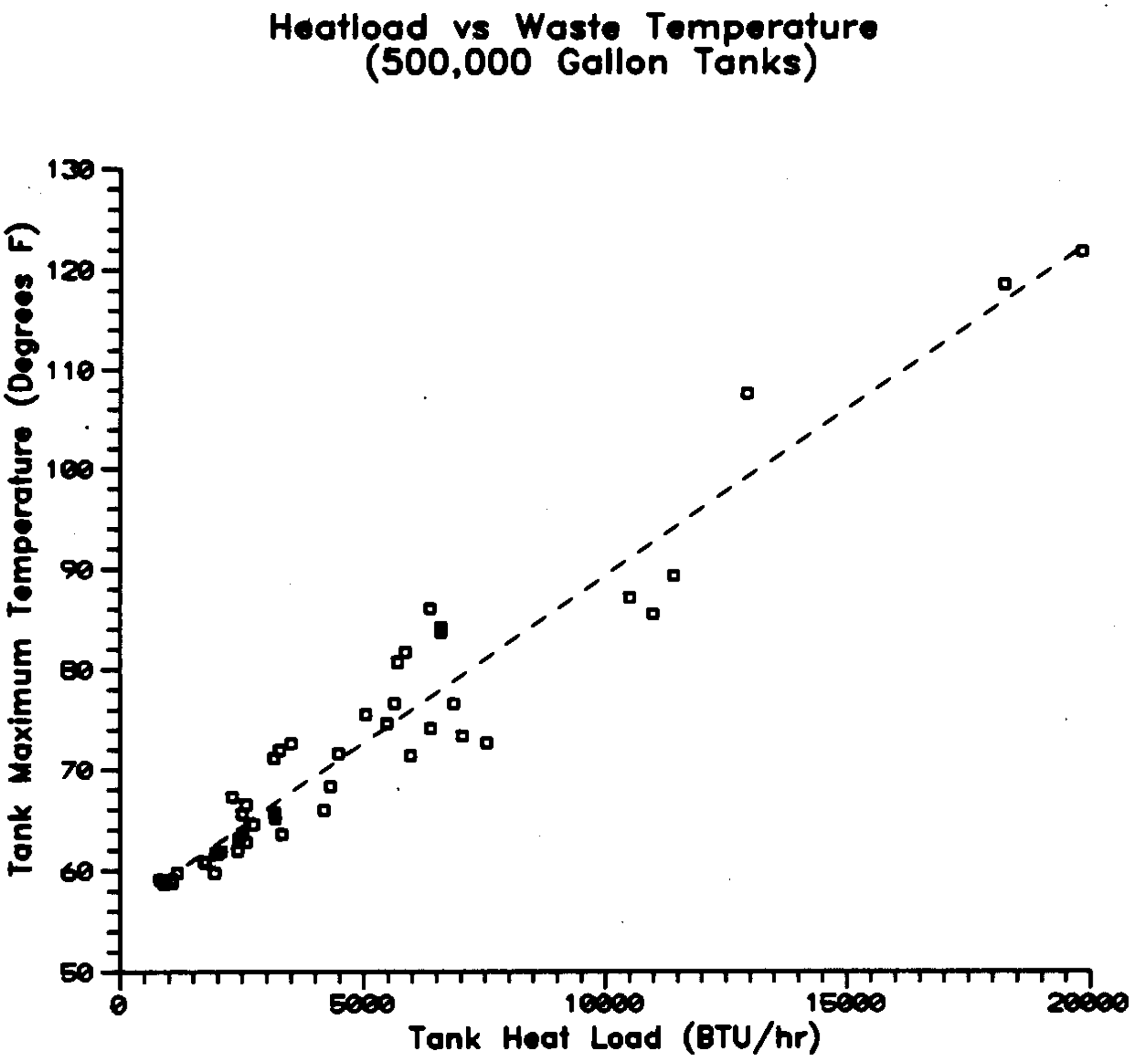


Figure 5. Waste Temperature vs Heat Load in 750,000-Gallon Single-Shell Tanks.

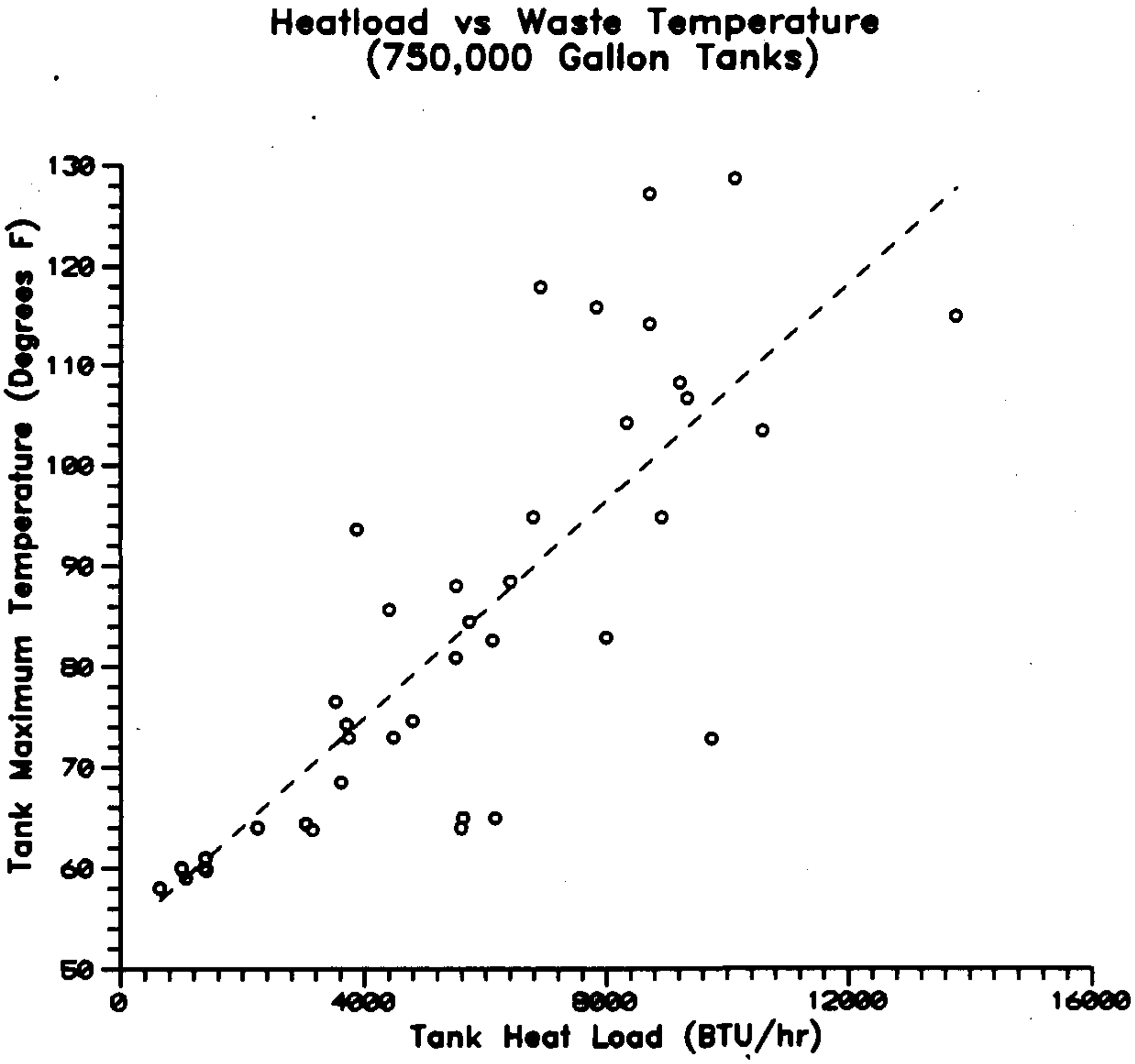
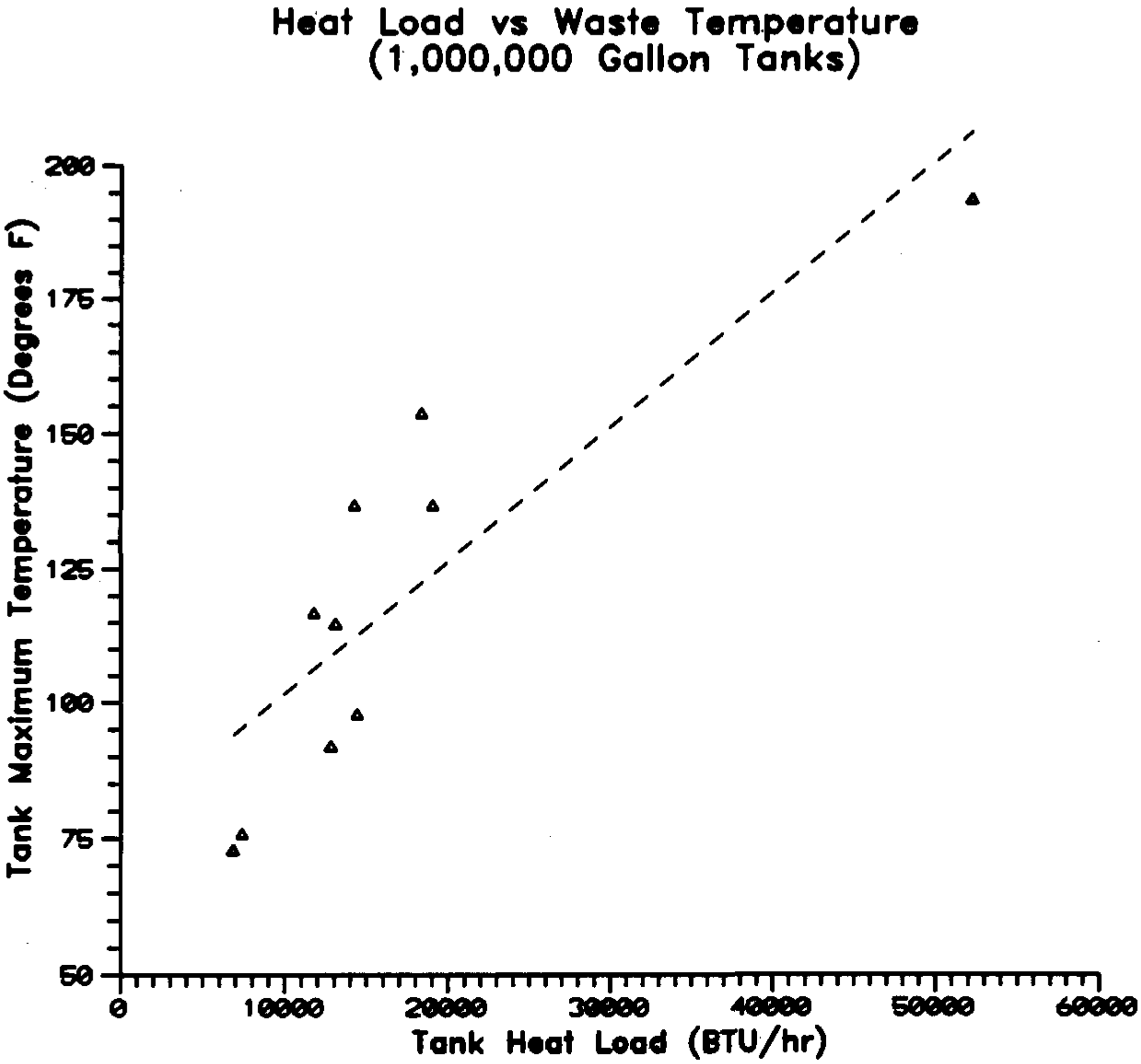


Figure 6. Waste Temperature vs Heat Load in 1,000,000-Gallon Single-Shell Tanks.



The method is conservative in that it overestimates the heat load for the following reasons:

- The heat conduction lengths used to estimate the heat being conducted through the bottom and side of the tank were chosen as the shortest distance to the surface. The heat out of the top of the tank would produce a temperature gradient such that the actual path lengths would be longer. This overestimates the heat out of the bottom and side of the tank.

- The temperature difference between the vapor space and the atmosphere is not adjusted for the small temperature drop between the vapor space and tank wall or soil and air and, is therefore overestimated.

4.2 HEAT LOADS IN VENTILATED TANKS

Ventilation is maintained on SSTs that are known or are suspected to have a high heat burden. The tanks with operating ventilation systems in the SST farms are tanks C-105, C-106, SX-101-112, and SX-114.

The total heat load of a tank with active ventilation can be roughly estimated by adding the conduction heat load to the amount of heat removed by ventilation. If the tank is assumed at steady state under ventilation, the conduction losses may be calculated by the method used for passively ventilated tanks. To estimate the amount of heat load removed by the ventilation systems, reliable data on the ventilation flow rates and the relative humidity of the tank vapor space must be known.

4.2.1 Tanks C-105 and C-106 Systems

Tank C-106 is actively ventilated due to high heat load. Tank C-105 is connected to tank C-106 through a cascade overflow line, and thereby receives ventilation from the same system. Water was formerly added to both tanks C-105 and C-106 to provide evaporative cooling. Tank C-106 was placed on a watch list in 1990.

The status of tank C-105 has been re-evaluated (Bander 1993b). The conservative heat load estimated was 7,300 W (25,000 BTU/h). Water additions to that tank were subsequently stopped. Active ventilation is still provided, however, because the ventilation system continues to operate for cooling of tank C-106. Tank C-104 also receives some cooling by this system through the cascade line between it and tank C-105.

A similar model was used to analyze the thermal situation in tank C-106 (Bander 1993a). Bander (1993a) concluded that a reasonably conservative estimate of the heat load in tank C-106 is 32,000 W (110,000 BTU/h).

4.2.1.1 Study of Ventilation Effects Using Tank C-106 Data. To apply the method used for passively ventilated tanks to the estimation of heat loads for the actively ventilated tanks, the amount of heat removed by the ventilation system at steady state must be added into the total heat equation. It was postulated that a correlation between the temperature fluctuations in the vapor space and the upper levels of the waste in a ventilated tank could provide an estimate of the total heat leaving the waste surface.

Temperature data obtained from tank C-106 included a period before and after the ventilation system was off (about 5 months at the beginning of 1992). This circumstance, and the availability of other analyses for comparison (Bander 1993a), made this tank an ideal candidate for testing the feasibility of the adapted method. The study concluded that psychrometric data for the ventilation inlet and outlet would be needed to fully specify the problem. With this data for each of the ventilated tanks, it should be possible to estimate those heat loads.

4.2.1.2 241-C-106 Waste Tank Vapor Space Temperatures. Tank 241-C-106 temperature data were investigated to determine if the amplitude temperature fluctuations in the vapor space could be used to define the effective heat transfer from the tank. Fourier series expansion coefficients were calculated for the temperature data from six thermocouples in riser 14 of tank 241-C-106 using a similar procedure as was used for the passively ventilated tanks (Crowe et. al 1993). The temperature data along with the data fit curves are shown in Figure 7.

All of the thermocouples show seasonal temperature variation. Like the passively cooled tanks, the vapor space temperature has a phase shift relative to the outside atmospheric variation. However, unlike the passively cooled tanks, no method has been found to relate the behavior of the vapor space temperature to thermal properties of the heat removal system for the actively ventilated tanks.

4.2.2 SX Tank Farm System

Most of the tanks in the SX Tank Farm are connected to the 296-S-15 exhauster (Leach and Stahl 1993). Flow from tanks SX-101 through SX-106 goes through underground ductwork into the vapor space of tank SX-109. Flows from tanks SX-107 through SX-112 and tank SX-114 connect to a common aboveground line to the exhauster.

Total heat loss from the SX Tank Farm ventilated tanks was calculated by summing the calculated loss by conduction with estimated ventilation losses. The tanks were assumed to be at steady state under ventilation. Conduction losses from these tanks were calculated from the vapor space temperatures by the method used for the unventilated tanks.

The portion of heat loss by ventilation was calculated using psychrometric measurements, taken May 24, 1994, from tanks SX-107 through SX-112 and SX-114. The data available for each of these tanks included wet- and dry-bulb temperature measurements for ambient air and for ventilation outlet, as well as volumetric flow rate at the outlet. Table 5 summarizes the outlet data used in the calculation. The inlet conditions used were the ambient measurements for that day and time, 23 °C (73 °F) dry-bulb temperature and 17 °C (62 °F) wet-bulb temperature.

Figure 7. Tank 241-C-106 Thermocouple Temperature Data.

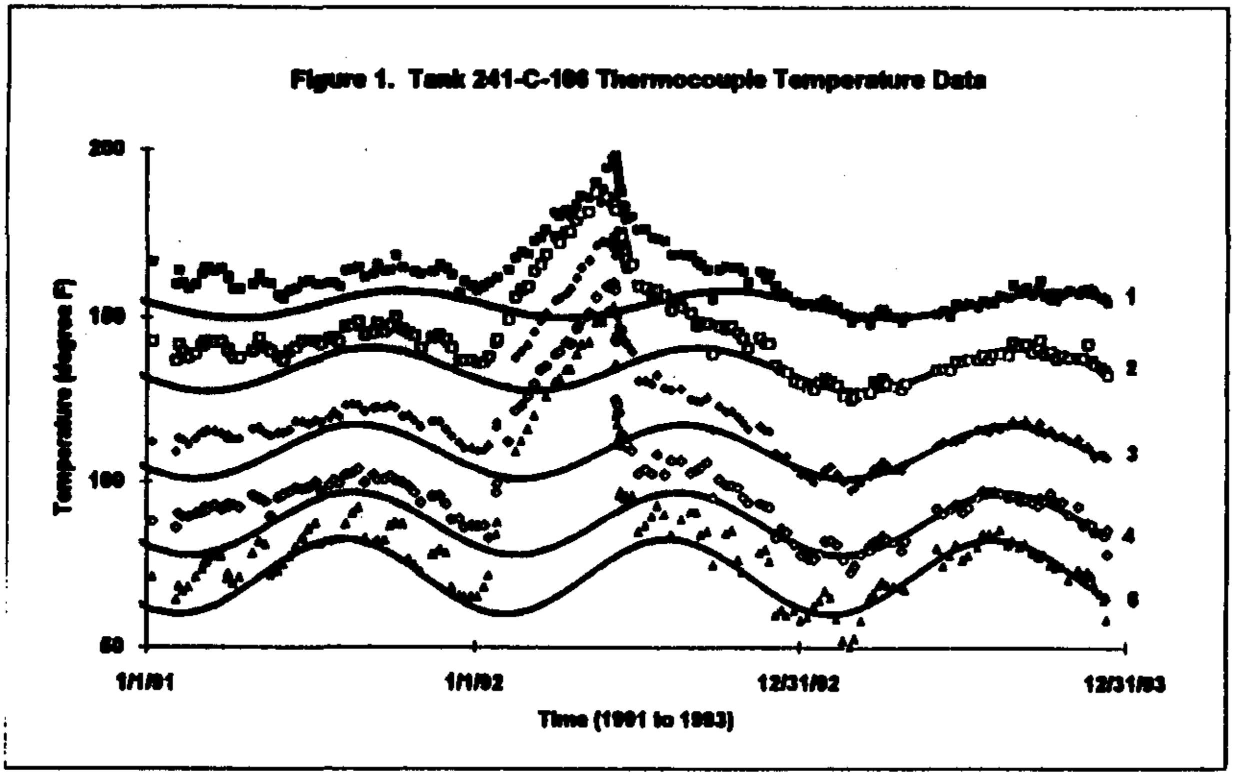


Table 5. Psychrometric Measurements at Exhaust Outlet for SX-Farm Tanks.

Tank	Exhaust dry-bulb temperature (°F)	Exhaust wet-bulb temperature (°F)	Exhaust airflow (ft^3/min)
SX-107	96	78	537
SX-108	95	75	581
SX-109	84	72	125
SX-110	98	78	312
SX-111	110	86	367
SX-112	104	80	243
SX-114	112	84	330

Measurements for tanks SX-101 through SX-106 were unavailable. The total flow through this part of the system was taken to be the measured flow rate at tank SX-109. The system flow was distributed amongst the tanks in proportion to the calculated distribution of the design flow (Wood 1994). The outlet conditions were taken to be dry-bulb temperature equal to measured vapor space temperatures, and 38% relative humidity. This was the average outlet relative humidity of the tanks for which measurements were available.

The inlet conditions for tank SX-109 were assumed to be the average of the vapor space temperatures from the six tanks feeding it, and 38% relative humidity. Inlet conditions for all other tanks were the measured ambient conditions.

The heat removed by ventilation was estimated by the following heat balance:

$$\dot{q} = \dot{m}\ (h_o - h_i)$$

where:

$\dot{q}$ = total heat rate removed by ventilation (BTU/h)
$\dot{m}$ = mass flow rate of dry air (lb_m/h)
h_i = specific enthalpy at inlet air conditions (BTU/lb_m dry air)
h_o = specific enthalpy at outlet air conditions (BTU/lb_m dry air).

The mass flow rate of dry air, $\dot{m}$, was taken to be the average of inlet and outlet specific volumes times the volumetric flow rate. Specific volume and specific enthalpy were taken from psychrometric tables. The temperatures and heat loads for the ventilated tanks are included as Table 6.

Table 6. Temperatures and Estimated Heat Loads for Actively Ventilated Single-Shell Tanks.

Tank	Capacity (gal)	Waste level (ft)	Waste volume (Kgal)	Vapor space temperature (°F)	Waste temperature (°F)	Conduction heat loss (BTU/h)	Ventilation heat loss (BTU/h)	Total heat load (BTU/h)
C-105[a]	500,000	5.2	150	83.1	90.4	NC	NC	25,000
C-106[b,e]	500,000	7.6	229	80.3	153.5	NC	NC	110,000
SX-101[d]	1,000,000	14.3	458	86.4	127.6	12,200	415	12,600
SX-102[d]	1,000,000	16.9	543	91.2	148.2	14,351	713	15,064
SX-103[c,d]	1,000,000	20.2	652	116.1	173.7	24,955	2,787	27,742
SX-104[d]	1,000,000	19.0	614	84.8	165.1	11,830	343	12,173
SX-105[d]	1,000,000	21.1	583	85.9	177.4	12,225	397	12,622
SX-106[c,d]	1,000,000	16.7	538	82.3	108.6	10,669	170	10,840
SX-107[e]	1,000,000	3.6	104	117.3	162.9	23,491	31,288	54,779
SX-108[e]	1,000,000	3.9	115	132.6	191.1	29,437	26,546	55,983
SX-109[d,e]	1,000,000	8.0	250	124.1	141.6	26,714	4,322	31,035
SX-110[e]	1,000,000	2.3	62	115.4	167.6	22,634	18,133	40,767
SX-111[e]	1,000,000	4.2	125	123.5	182.7	25,982	35,031	61,013
SX-112[e]	1,000,000	3.2	92	122.3	154.7	25,391	16,203	41,594
SX-114[e]	1,000,000	5.9	181	135.0	181.9	30,685	28,007	58,692

Note: To convert from BTU/h to watts, divide by 3.413.

[a] Bander 1993b.

[b] Bander 1993a.

[c] Organic watch list tank.

[d] Flammable gas watch list tank.

[e] High heat tank.

N/A = not available.

NC = not calculated.

4.3 CONCLUSIONS ON HEAT LOAD ESTIMATES

Of the SSTs that are not on active ventilation, all of the calculated heat loads are well below 11,700 W (40,000 BTU/h), except for tank A-104, with an estimated heat load of 15,200 W (52,000 BTU/h). This tank is on the list of tanks with high heat loads (>11,700 W [>40,000 BTU/h]) (Hanlon 1994), and was formerly on active ventilation. Because there are problems with the ventilation system in the A Tank Farm, it has not been operated for at least 2 years, and may not operate again. The waste depth in tank A-104 is shallow (0.3 m [0.9 ft]). Consequently there is sufficient heat transfer to the vapor space, so that the maximum waste temperature at steady state (90 °C [194 °F]) is well below the 149 °C (300 °F) LCO.

For the tanks with significant inventories of reactive chemicals, those on the ferrocyanide and organic watch lists, waste temperatures below 90 °C (194 °F) must be ensured. All the passively ventilated tanks that are currently on these lists have estimated heat loads and measured waste temperatures that place them within that criterion.

SSTs on active ventilation include tanks C-105, C-106, SX-101 through SX-112, and SX-114. Of these, Tank C-106, tanks SX-107 through SX-112, and SX-114 are listed as tanks with heat loads >11,700 W (>40,000 BTU/h) (Hanlon 1994). This analysis confirmed heat loads >11,700 W (>40,000 BTU/h) for those tanks, except for SX-109. Its estimated heat load was 9,000 W (31,000 BTU/h). The waste temperature in these tanks could approach the 149 °C (300 °F) LCO if ventilation is lost. The time to reach that temperature was estimated for a bounding case. The analysis and its results are discussed in Section 6.0.

Tanks SX-106 and SX-103 are also on the watch list for tanks with high amounts of organic salts. Both of these tanks have estimated heat loads around 7,900 W (27,000 BTU/h). The waste temperature in tank SX-103 is 79 °C (174 °F). There is a potential for both of these tanks to exceed the 90 °C (194 °F) limit if ventilation is lost. The time it will take for tank SX-103 to reach the 90 °C (194 °F) limit was estimated and is discussed in Section 6.0.

5.0 ESTIMATES OF ALLOWABLE HEAT LOADS

Limiting condition for operation (LCO) maximum temperature in an SST is 149 °C (300 °F) (Dougherty 1994). This limit has been set to maintain temperatures in the tank concrete structure low enough that the structural integrity of the tank is not compromised. For the tanks on watch lists because of their reactive chemical content (ferrocyanide and organic compounds), maximum waste temperatures of 90 °C (194 °F) must be ensured to prevent loss of moisture (Postma et al. 1994; Babad and Turner 1993).

5.1 BASIS FOR HEAT LOAD LIMITS

Estimates of maximum waste temperatures for different heat loads were made in 1981 (Campbell 1981) using a finite difference thermal analysis computer code (HEATING5). Campbell (1981) assumed the waste material to be a slab with uniform thickness, thermal properties, and power density. The thermal properties were for dry material and were assumed not to vary significantly with temperature. Use of thermal properties for dry material is conservative in that it tends to overestimate the maximum waste temperature for a given heat load. Those results indicated that for a tank with 9 m (30 ft) of waste, the maximum heat load to maintain below 149 °C (300 °F) in the waste is about 9,400 W (32,000 BTU/h). For 4.6- and 1.8-m (15- and 6-ft) depth, the maximum heat loads are 10,200 and 11,700 W (35,000 and 40,000 BTU/h), respectively.

5.2 FINITE ELEMENT ESTIMATES

To further examine the relationship of tank heat load and maximum waste temperature in a passively ventilated SST, a three-dimensional finite element model of a 500,000-gal (1,900,000-L) tank was used. The model was constructed and analyzed using the COSMOS/M[1] finite element code on a personal computer.

The model represents a one-quarter section of the tank with the soil surrounding it. The outer boundary was chosen as 15 m (50 ft) from the tank centerline. This is approximately the halfway distance between tanks in the farms. An adiabatic condition (no heat flux across the boundary) was chosen for this boundary. This represents a tank with tanks just like it on all four sides. The other two vertical boundaries were also given adiabatic constraints to represent the radial symmetry of the model.

A constant temperature, 287 K (56.3 °F), was imposed at the ground surface. This is the average of the seasonal temperature fluctuations derived from atmospheric data for the 2-year period between January 1990 and January 1993 (Crowe et al. 1993). The same temperature was imposed on the lower boundary of the model, 60 m (about 200 ft) below the surface, to represent transfer to the water table. A sensitivity study to examine the

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[1] COSMOS/M is a registered trademark for Structural Research and Analysis Corporation, Santa Monica, California.

effect of making the lower surface adiabatic showed that this choice of boundary condition had minimal effect on temperatures in or near the tank.

The model contains three areas to represent the waste, the vapor space and the soil. The thermal conductivity of the soil was taken to be 1.04 W m^{-1} K^{-1} (0.6 BTU h^{-1} ft^{-1} $°F^{-1}$). This is a value derived from a study of the temperature variations between the atmosphere and the vapor spaces of unventilated tanks (Crowe et al. 1993).

The waste was modeled as wet sludge, with a thermal conductivity of 0.5 W m^{-1} K^{-1} (0.29 BTU h^{-1} ft^{-1} $°F^{-1}$) (Grigsby et al. 1992). Campbell (1981) assumed a somewhat lower waste conductivity, 0.43 W m^{-1} K^{-1} (0.25 BTU h^{-1} ft^{-1} $°F^{-1}$). To test the sensitivity of the model to waste conductivity, several cases were run using a conductivity value compatible with that of dry salt cake, 0.25 W m^{-1} K^{-1} (0.15 BTU h^{-1} ft^{-1} $°F^{-1}$) (Grigsby et al. 1992), because many of the tanks contain a layer of dry salt cake. Maximum temperatures achieved were 10% higher for the 11,700-W (40,000-BTU/h) heat load, and the difference diminished with the heat load.

The predicted waste temperatures were compared with actual waste temperatures from tanks for which heat loads were estimated from the vapor space temperatures (see Chapter 4.0). It was found that the tank temperatures do not approach the temperatures calculated using the conductivity value for dry salt cake. Therefore, the conductivity value for wet sludge was chosen for subsequent comparison of cases.

The vapor space air was given a very high conductance value to simulate the thermal uniformity of the vapor space, as shown by tank temperature measurements. Figures 8 and 9 show the predicted relationship of waste temperature to heat load for two representative waste depths (2.4 and 4.6 m [8 and 15 ft]) in a 500,000-gal (1,900,000-L) tank. The SSTs with waste depths corresponding to the depths chosen for the analysis are also included in the plots. The model, in general, predicts higher temperatures than are actually experienced in the waste. Figure 10 displays the estimates of tank heat load versus maximum tank temperature for three representative waste depths.

5.3 CONCLUSIONS ON ALLOWABLE HEAT LOADS

The results of the model indicate that, for waste depths up to 4.6 m (15 ft), and heat loads less than 11,700 W (40,000 BTU/h), passive cooling will maintain the waste temperatures below the 149 °C (300 °F) LCO for tank integrity. All of the SSTs, except for tank A-101, have waste depths less than 6.9 m (22.7 ft). Extrapolating the model data to a waste depth of 6.7 m (22 ft) indicates that the model prediction for maximum waste temperature would be about 156 °C (312 °F) for a 11,700-W (40,000-BTU/h) tank. These model predictions confirm that SSTs with heat loads above 11,700 W (40,000 BTU/h) should receive active cooling to prevent violating the administrative limit for waste temperature.

Tanks containing significant concentrations of reactive chemicals (ferrocyanide and organic compounds) require a lower temperature criterion. Documentation of criteria to be used for classifying these tanks in regard to

Figure 8. Maximum Waste Temperature Predictions for 8-Foot Waste Depth.

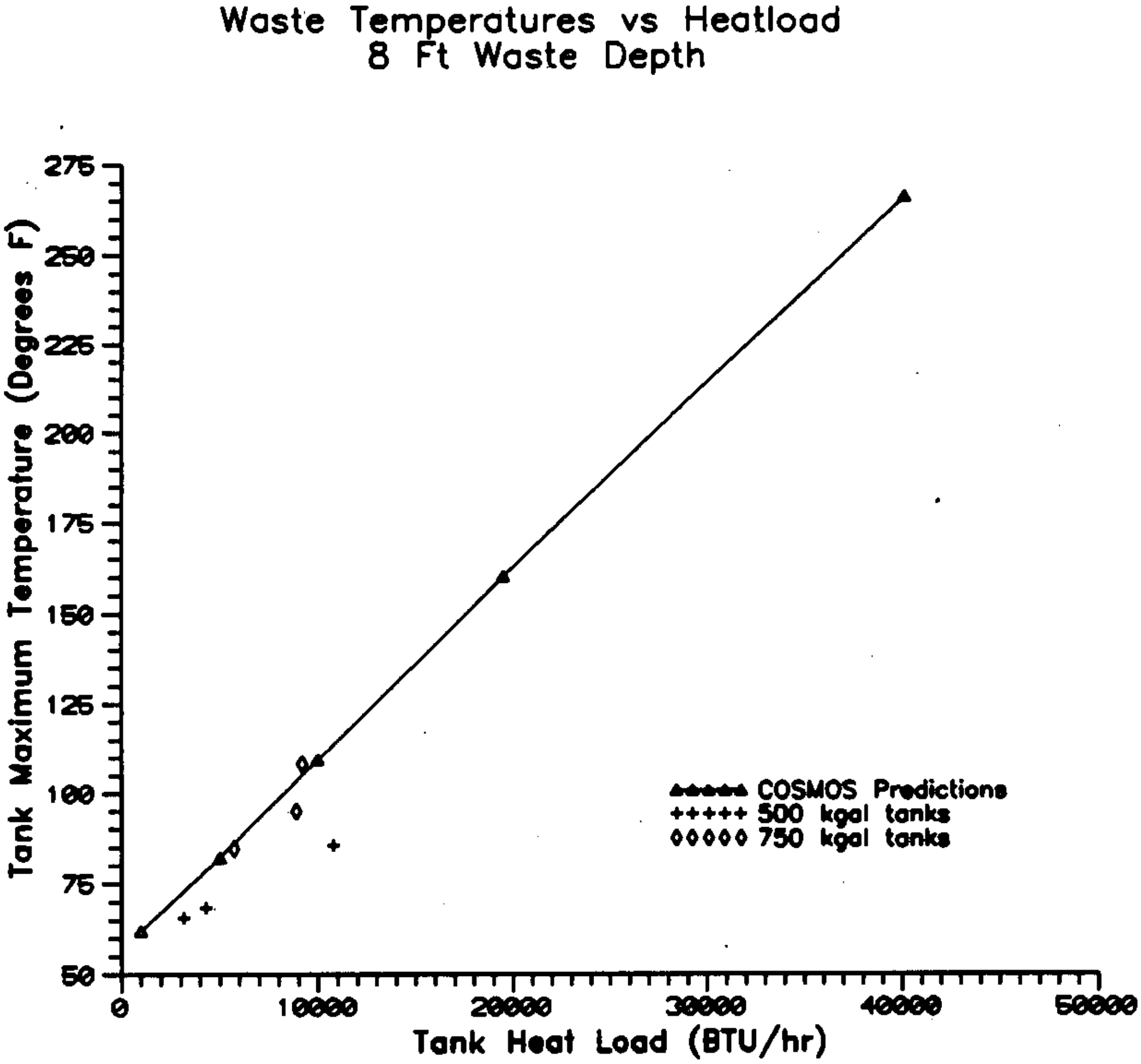


Figure 9. Maximum Waste Temperature Predictions for 15-Foot Waste Depth.

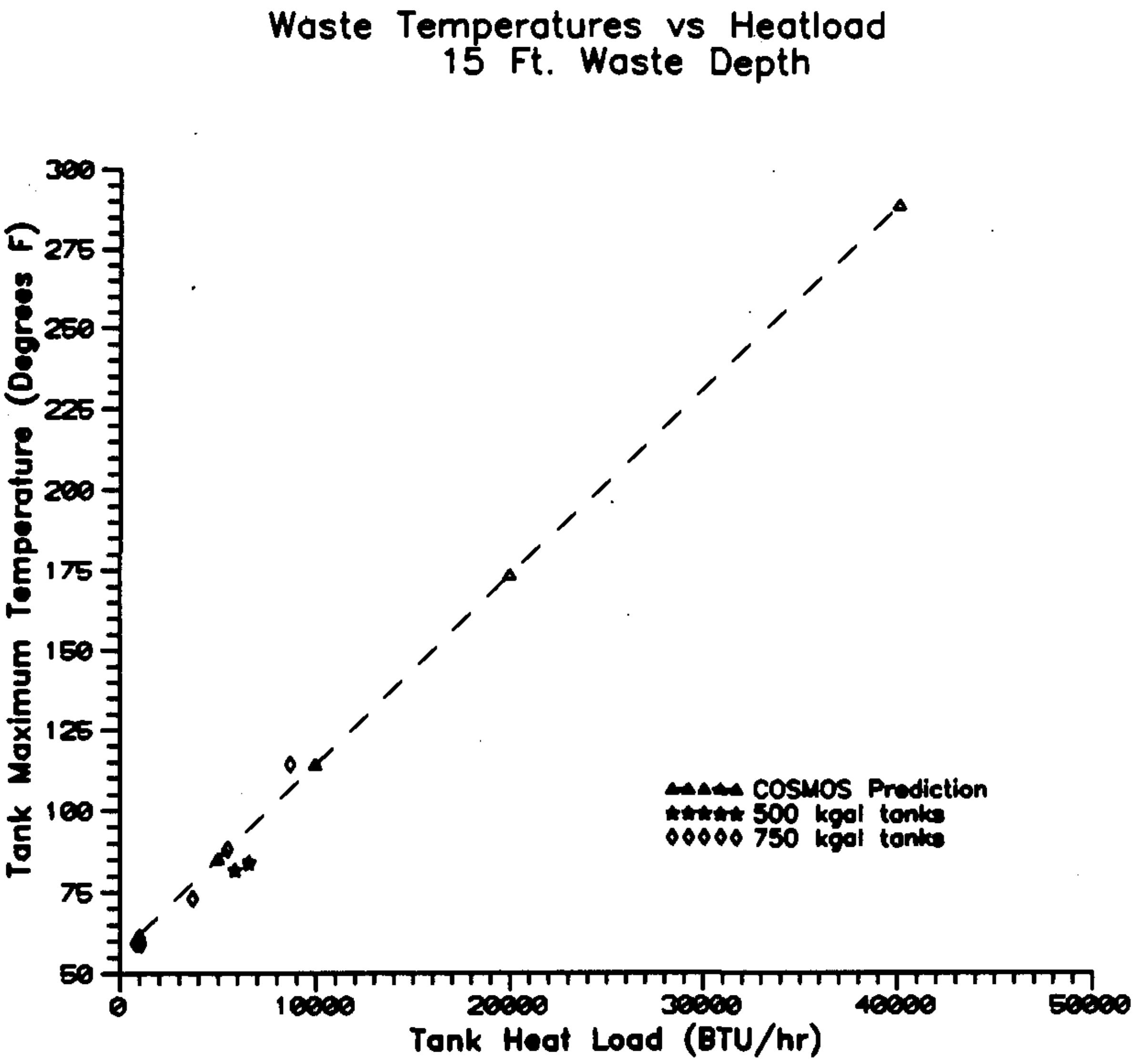
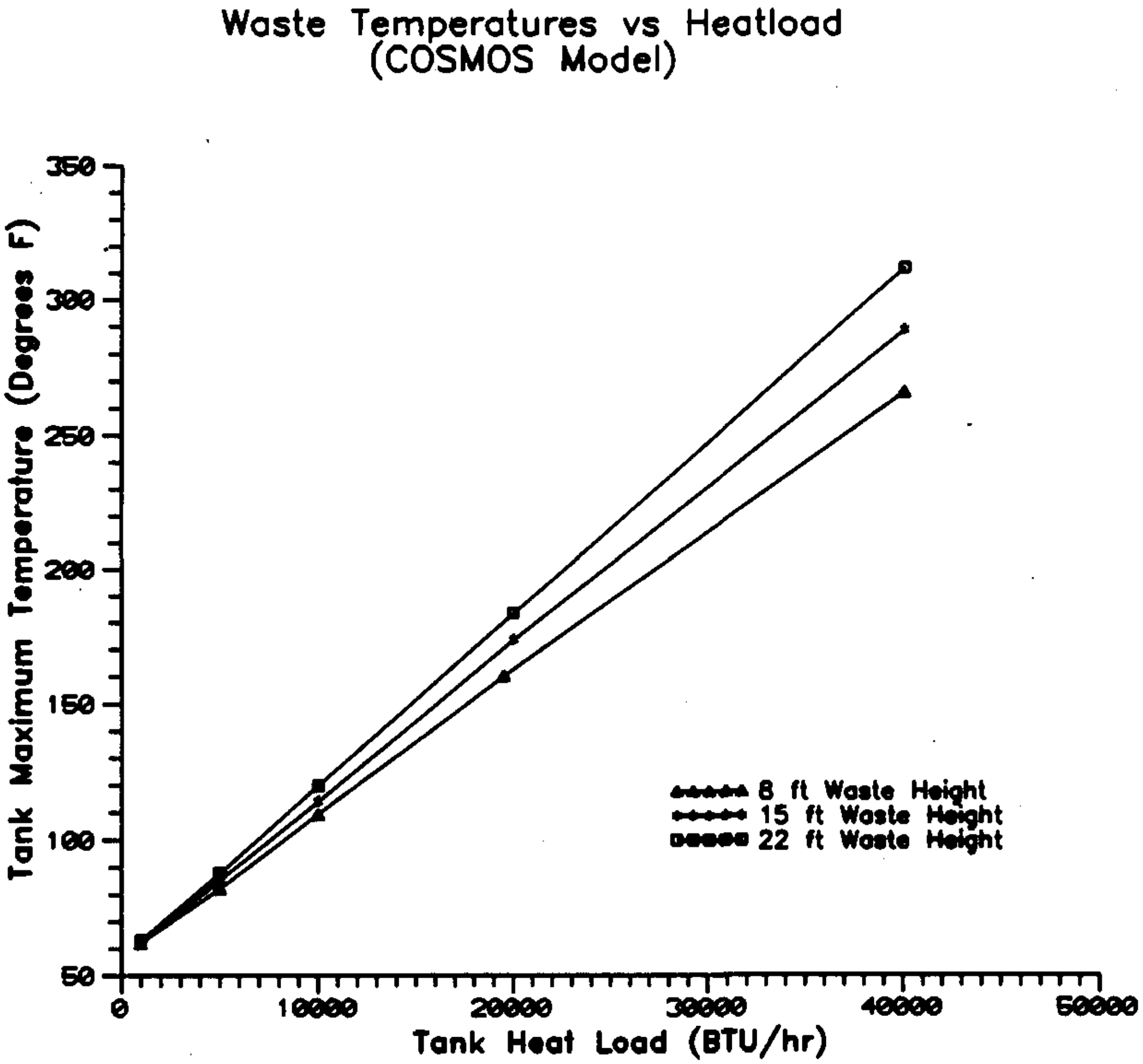


Figure 10. Waste Temperature vs Heatload (COSMOS Model).



their safety require that waste temperatures of <90 °C (<194 °F) be maintained to hold the tank in a conditionally safe status (Postma et al. 1994; Babad and Turner 1993).

The highest waste temperature in any of the passively ventilated SSTs on either the ferrocyanide or organic watch list, is 68 °C (154 °F) in organic tank A-101. This includes all of the tanks that are currently on either watch list, except for tanks SX-106 and SX-103. These tanks are on the organic watch list and have temperatures, under ventilation, of 46 and 79 °C (114 and 174 °F), respectively.

6.0 TANK RESPONSE TO LOSS OF COOLING

SSTs that have radioactive heat loads high enough that waste temperatures could reach either the 149 °C (300 °F) LCO, or the 90 °C (194 °F) criterion for tanks with reactive waste, are candidates for active cooling. Most of the high heat tanks, tanks with greater than 11,700-W (40,000-BTU/h) heat loads, are currently on active ventilation.

With two exceptions, the tanks on watch lists because they contain significant amounts of reactive chemicals (ferrocyanide or organic compounds) all have steady-state heat loads and temperatures well below those of concern, even on passive cooling. Tanks SX-103 and SX-106, organic tanks, are actively ventilated. Their waste temperatures are currently below 90 °C (194 °F). However, because their estimated heat loads are greater than 5,860 W (20,000 BTU/h), their waste temperatures could potentially exceed that limit if active cooling is lost.

6.1 RATE OF TEMPERATURE RISE

If a tank requires active cooling to keep the waste temperature below either of the temperature limits, the time it will take to approach the limit if cooling is lost must be characterized. Estimates can come from both analysis and field data.

6.1.1 Bounding Case for Tank Integrity Limit

Tank C-106, with an estimated heat load of 32,200 W (110,000 BTU/h), is the bounding case to characterize the time within which active cooling must be restored to maintain 149 °C (300 °F) waste temperature.

Observation of the temperature response in tank C-106 when ventilation was off gives a practical indication of the rate of temperature rise. The maximum tank temperature rose from about 68 to 92 °C (155 to 197 °F) over approximately 160 days. The average rate of temperature rise was 0.15 °C/day (0.3 °F/day). If the temperature increase remained nearly linear with time, the tank would be expected to reach 149 °C (300 °F) about 480 days after active cooling was lost.

In fact, the rate of temperature increase is expected to decrease with time, approaching zero as the system approaches the steady state. This is because the tank will eject more heat to the surroundings as its temperature increases. Therefore, extrapolating the nearly linear early response to times later in the problem overestimates the total temperature increase. Consequently, the time to reach higher temperatures is expected to be longer than estimated.

A transient analysis, using the finite element model described in Section 5.0, estimated the temperature rise from SST conditions that approximated tank C-106. The initial conditions were the steady-state temperatures for 2.5 m (8 ft) of waste and 5,860-W (20,000-BTU/h) heat load.

The heat load was increased to 29,300 W (100,000 BTU/h), and the transient temperature response for about 3 years was estimated.

The initial waste temperature was 344 K (159 °F), very close to the actual tank C-106 condition before loss of ventilation. The tank C-106 waste height is 2.3 m (7.6 ft). Therefore, the model results should approximate the field data.

The temperature rise predicted by the model for the first 160 days after ventilation was lost was 60 °C (110 °F). This is about 2.5 times higher than the rate of temperature rise observed in the tank C-106 data. The model predicted that it would take about 240 days to reach 149 °C (300 °F). The thermal response is very sensitive to the thermal conductivity of the waste. A previous analysis (Bander 1993a) found a good match to the tank C-106 data using waste thermal conductivities 1.7 to 3.4 times higher than those used for this analysis.

6.1.2 Bounding Case for Reactive Waste Limit

Of the SSTs with reactive waste (ferrocyanide and organic tanks), only SX-103 and SX-106 are on active cooling systems. The rest of the ferrocyanide and organic tanks have heat loads low enough that waste temperatures are maintained below 90 °C (194 °F) by passive heat rejection. Of the two, tank SX-103 has the higher waste temperature, about 82 °C (180 °F), under active ventilation.

The same finite element model used to characterize the transient response of tank C-106 was used to estimate the rate of temperature rise after loss of cooling in tank SX-103. Starting at an initial waste temperature of 360.5 K (189 °F) and a heat load of 8,200 W (28,000 BTU/h), the tank transient response was observed.

The model predicted that the maximum waste temperature would reach 90 °C (194 °F) in 185 days. This estimate can be considered conservative, because the same model overpredicted the rate of temperature rise for tank C-106, and because the initial temperature at loss of cooling was somewhat higher than the tank SX-103 waste temperature.

6.2 CONCLUSIONS ON RESPONSE TO LOSS OF COOLING

Both field data and model results indicate that the rate of temperature rise for the SST with the highest heat load provide long time periods before cooling must be restored. The transient is sensitive to waste thermal conductivity, heat load, and tank waste level. The tank C-106 analysis will be re-run with a higher thermal conductivity to better match the data.

This is expected to be the bounding case for the structural temperature limit. A further set of cases will envelope the heat loads and waste height combinations for the reactive chemicals criterion.

7.0 LOSS OF VENTILATION IN DOUBLE-SHELL TANKS

A potential release from a DST could occur if the waste were allowed to reach, and remain at, boiling temperature for an extended period of time without ventilation. After ventilation is lost, the vapor space pressure would quickly equalize with the atmosphere. As the waste heats up, the temperature and pressure in the vapor space would also rise, and air would flow out through the unfiltered inlet leak paths.

The magnitude of the release and its consequences depend on a number of factors. The nature of the boiling, i.e., vigorous mechanical agitation or "simmering," and mechanisms for retaining waste aerosols inside the tank, will affect the amount of waste material entrained in the air exiting the tank.

Detailed modeling of the processes involved in waste boiling need to be performed to investigate likely releases during a boiling event. Subsequent risk analysis of the event would determine both the likelihood and consequences of the releases, and whether restricting tank temperatures to below the boiling temperature should be an Operational Safety Requirement. This risk analysis is recommended for future work.

A first-order analysis estimated the minimum time required for the DSTs, with their present waste conditions, to reach boiling (100 °C [212 °F]) after active cooling is lost. Assuming adiabatic heatup, that is, all waste power is dedicated to raising the waste temperature, with no heat loss to the environment, provides the most conservative estimate of the heatup rate.

The time to boiling under adiabatic conditions was calculated according to the following equation:

$$t_b = (C_l \, V_l \, \rho_l + C_s \, V_s \, \rho_s)(212 - T)\left[\frac{1}{Q}\right]$$

where

t_b = time to adiabatic boiling (hours)
C_l = heat capacity of tank liquid (0.8 BTU lbm^{-1} $°\text{F}^{-1}$)
V_l = liquid volume of tank, supernate + slurry (gal)
ρ_l = density of liquid (10.8 lb_m gal^{-1})
C_s = heat capacity of tank sludge (0.72 BTU lbm^{-1} $°\text{F}^{-1}$)
V_s = sludge volume of tank (gal)
ρ_s = density of sludge (13.3 lb_m gal^{-1})
T = tank waste temperature (°F)
Q = tank heat load (BTU/h).

Values for the volumes of liquid, slurry, and sludge in the tanks, as well as waste temperatures, are from Hanlon (1994). Tank heat loads were calculated from radionuclide concentrations of tank samples (Leach and Stahl 1993).

Five tanks in the AP Tank Farm had no reported radionuclide concentrations. The waste in tanks AP-101, -106, -107 and -108 is dilute non-complexed waste. This is low activity liquid waste originating from T and S Plants, the 300 and 400 Areas, PUREX facility (decladding supernate and miscellaneous wastes), 100 N Area (sulfate waste), B Plant, saltwells and PFP supernate. Tank AP-105 contains 820 gallons (3100 L) of Double-Shell Slurry Feed.

The maximum waste temperatures in these five tanks are all below 16 °C (60 °F), indicating that the waste has very low heat load. Tanks AP-101, -106, -107, and -108 are all filled nearly to capacity. Future waste additions, if any, would not increase their heat loads significantly. Therefore, time to boiling in those tanks was assumed to be >100 years, as calculated for AP-102 and AP-103 which also contain the dilute non-complexed waste.

Tank AP-105 still has much of its capacity available to receive wastes in the future. Since the added wastes could increase the heat load significantly, this tank was assumed to be 20,500 W (70,000 BTU/h), the maximum heat load allowed for any AP tank by administrative control, AC 5.19 (Heubach 1994). The heat load values for SY-101 and SY-103 are taken from Fox et al. (1993).

Table 7 lists the data for the DSTs in the AN, AP, AW and SY Tank Farms.

All the DSTs are active and potentially will receive additional waste in the future. Procedural controls currently regulate waste additions such that the heat load of any tank in the AN, AP and AW Tank Farms remains below 20,500 W (70,000 BTU/h). The heat load of any tank in the SY Tank Farm is kept below 15,000 W (50,000 BTU/h).

For the tanks in the AN, AP and AW Tank Farms, the minimum time to boiling under present tank conditions is about 2 years for tank AN-103. A tank filled to its capacity (4,400,000 L [1,160,000 gal]), with the maximum allowed heat load, would have a waste power density of 0.06 BTU/h/gal. The minimum time to boiling, assuming initial waste temperature of 38°C (100 °F), is about 1.8 years. For the SY Tank Farm, the maximum power density for a filled tank is 0.04 BTU/h/gal. If waste with power density below these limits is added to any tank, the minimum time to adiabatic boiling will not be less than 1.8 years.

Controls also limit waste temperatures in all these tanks to below boiling temperatures, and tank temperatures are routinely monitored (Heubach 1994). In addition, controls on ventilation operation are in place, to maintain tank pressure lower than atmospheric and to prevent accumulation of flammable gases in the tank atmosphere (Heubach 1994). The maximum allowed ventilation outage time is currently 2 hours. This is much less than the time required for a tank to heat up to boiling.

Table 7. Data for Estimating Time to Adiabatic Boiling for Double-Shell Tanks. (2 sheets)

Tank	Liquid volume (Kgal)	Sludge volume (Kgal)	Waste temperature (°F)	Heat load (BTU/h)[a]	Time to boiling (years)
AN-101	718	0	70	8,000	12.6
AN-102	1,002	89	106	41,000	2.8
AN-103	953	0	118	45,000	2.0
AN-104	793	264	122	40,000	2.4
AN-105	1,132	0	116	25,000	4.3
AN-106	4	17	63	65	51.6
AN-107	932	134	101	27,000	4.4
AP-101	1,060	0	57	NA[d]	>1,000
AP-102	1,103	0	83	0.05	>1,000
AP-103	1,131	0	57	2.5	>1,000
AP-104	18	0	58	0.6	>1,000
AP-105	820	0	70	70,000[b]	1.6
AP-106	1,128	0	64	NA[d]	>1,000
AP-107	1,110	0	54	NA[d]	>1,000
AP-108	1,131	0	61	NA[d]	>1,000
AW-101	1,053	84	101	32,000	3.9
AW-102	978	1	61	4,000	37
AW-103	284	363	64	290	350
AW-104	833	179	74	37,000	3.8
AW-105	747	297	66	1,700	91
AW-106	813	211	66	9,400	16
SY-101	542	0	119	40,000[c]	1.2
SY-102	653	71	66	2,000	53
SY-103	739	0	98	23,500[c]	3.5

[a] Except where noted, heat loads were calculated from radionuclide data for tank samples.

[b] No available sample data; administrative control heat load assumed.

[c] Fox et al. 1993.

[d] No reported radionuclide data; tank contains dilute non-complexed waste. Therefore, time to boiling was assumed to be similar to that for other tanks containing that waste.

A combined violation of the maximum allowable tank heat load, undetected rise in temperature, and ventilation outage for greater than 2 years appears unlikely. Further analysis to quantify the likelihood of conditions that would allow a DST to reach boiling is warranted. If a series of events that would allow tank boiling is found to be credible, more detailed analysis will be needed to characterize the expected releases from the tank and estimate the consequences of the release.

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