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7. Abstract

An analysis was performed to determine the optimum ventilation line up for the AN Tank Farm. The analysis used the postulated maximum historical GRE in tanks AN-103, -104, and -105. Tank AN-104 was found to be limiting. The results of the analysis show that an airflow of 250 cfm through tanks 241-AN-103, -104, and -105 with an airflow of 100 cfm through tanks 241-AN-101, -102, -106, and -107 would be the optimum ventilation lineup.

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FLAMMABLE GAS SAFETY PROGRAM: ANALYSIS OF GAS SAMPLING PROBE LOCATIONS IN THE SX-FARM FLAMMABLE GAS WATCHLIST TANKS

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**FLAMMABLE GAS SAFETY PROGRAM:
ANALYSIS OF GAS SAMPLING PROBE LOCATIONS IN THE
SX-FARM FLAMMABLE GAS WATCHLIST TANKS**

1.0 INTRODUCTION

1.1 PURPOSE

Seven of the fifteen tanks in the SX-Farm have been placed on the Flammable Gas Watchlist. Gas sampling probes have been placed in these tanks, located in the ventilation inlet risers. The purpose of this report is to document a series of analyses that estimate the hydrogen gas concentrations at the probe locations compared to the concentrations that exist in the tank airspace.

1.2 BACKGROUND

There are seven Flammable Gas Watchlist tanks in the SX-Farm. These tanks are: 241-SX-101, -102, -103, -104, -105, -106, and -109. In order to more accurately determine the hydrogen gas concentrations in these tanks, a sampling probe has been placed in each tank. Because no other tank openings were available, these probes were placed in the ventilation inlet risers and the sampling point was located close to the surface of the waste. Because these probes were located in the inlet risers, concern was raised about the effect of the inlet airstream on the hydrogen gas concentration measurements by the sampling probes. Consequently, an analysis effort was directed to determine what perturbations of the hydrogen gas concentration measurements could be expected.

2.0 OVERVIEW

2.1 DESCRIPTION OF ANALYSIS

The determination of the airflow patterns in the airspace of the SX-Farm tanks required an estimation of the ventilation airflow into and out of the tank, as well as the temperatures of the waste surface and the tank dome surface. A model of each SX tank of interest was created for use with a heat transfer code, HEATING7. The results of the analyses of these models estimated the total heat load of the tanks and the heat losses from the tanks due to evaporation and convection. These results were then used with a model of the SX-Farm created for the GOTHIC code to estimate the ventilation flow necessary to remove the required evaporation and convection heat. A three-dimensional model of the airspace in an SX-Farm tank was created for the GOTHIC code. The ventilation airflow and waste and dome surface temperatures were used with this model to estimate the airflow patterns within the tank airspace. These airflow patterns were then used with the ventilation airflow

to estimate the perturbation of the ventilation airflow jet. With the ventilation airflow perturbations estimated, the concentrations of tank airspace gas within the ventilation airflow jet could be estimated. These estimations were then evaluated for the location of the hydrogen gas probe to determine the ratio of gas seen at that location versus the tank airspace gas concentrations.

2.2 SUMMARY OF RESULTS

The concentration of hydrogen in the gas measured by the hydrogen detectors in the Flammable Gas Watchlist tanks is estimated to be at least 80 percent of the concentration in the tank atmosphere. The hydrogen is well mixed with the gas in the airspace of a tank, except for a short period of time when the hydrogen is released from the waste during a gas release event. The time of inhomogeneous mixing would depend upon the release rate of the hydrogen from the waste.

3.0 MODEL DESCRIPTIONS

3.1 METHODOLOGY

Evaluation of the accuracy of the tank hydrogen gas concentration measured at the probe location requires good estimations of the airflow patterns within the tank airspace. These airflow patterns are perturbed by the ventilation inlet airflow, which is in the form of a vertical jet of low velocity, around 2 m/s (7 ft/s), directed from the tank dome downwards towards the waste surface.

These ventilation airflows were estimated from the evaporative and convective heat losses from the tanks. These losses were estimated by use of a two-dimensional heat transfer model used with the HEATING7 code. This model had been previously used for heat load evaluations for the ferrocyanide tanks and has been rigorously documented (McLaren 1993, 1994a). The model was modified to describe the SX-farm tanks. The heat loads of the tanks and the evaporative and convective heat losses were estimated by matching predictions of the temperature versus height with known temperature data. These heat losses were then input into a GOTHIC model of the SX-farm tanks. Ventilation airflows through the tanks were modified until the airspace temperatures within the tanks remained constant over a long period of time (ca. 1.0×10^6 seconds) to ensure that any transient effects had settled out. These ventilation airflows were then input into a three-dimensional model to evaluate their effects on the circulation patterns within the tank airspace.

3.2 TANK CONDUCTION MODEL

In order to determine how much heat from a waste storage tank is lost through evaporation and convection, a model that accounted for all methods of heat loss and their sinks was created. This model used the HEATING7 heat

transfer code. HEATING7 is the latest in a series of upgrades of the original HEATING code, and is a finite difference heat transfer code that will compute heat transfer in up to three dimensions and in three different geometries. The model created for this code is a modification of a model created to estimate the heat loads of the Ferrocyanide Watchlist tanks, and has been extensively documented and reviewed (McLaren 1993, 1994a). The modifications required to model the SX-Farm tanks were simple and few in number.

3.2.1 Description of the Model

The model created of a single SX-Farm tank included the tank concrete walls, floor, and dome, the waste contents, and the soil over, under, and surrounding the tank. The sinks to which the tank heat was rejected were the atmosphere and the water table beneath the tank. The model was created in Cartesian coordinates in two dimensions, so boundary curves had to be described as steps. A noding diagram of the model is shown as Figure 1. The model includes radiative and convective heat transfer from the surface of the waste to the tank dome. The convective heat transfer is obtained by specifying a natural convection heat transfer coefficient on the waste surface and the dome surface. There is no convective heat transfer to the sides of the tank. Radiative heat transfer is obtained by specifying a radiative heat transfer coefficient on the waste surface and dome surface. There is no radiative heat transfer to the tank walls. The simplification of the radiative and convective heat transfer is a second order effect. The studies of the effects of simplifying the radiative heat transfer in the tank vapor space are documented in (McLaren 1993).

3.2.2 Boundary Conditions

The tank is bounded on all four directions. The tank centerline is a reflected boundary, as the model is symmetric. The outer vertical boundary is an adiabatic boundary at 17.54 m (57.5 ft). This boundary distance is calculated from the spacing between the tanks in the farm and reducing the rectangular area to a circular one. The upper boundary is the atmosphere. This boundary is described as a surface heat transfer coefficient of $11.4 \text{ W/m}^2\text{-}^\circ\text{C}$ ($2.0 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$) rejecting to a constant temperature of $12.2 \text{ }^\circ\text{C}$ ($54 \text{ }^\circ\text{F}$). This is the temperature of the atmosphere as averaged over 63 years. The heat transfer coefficient describes an average 12.9 kph (8 mph) wind at the surface of the soil. The lower boundary is the water table. It is described as a constant temperature sink at $12.8 \text{ }^\circ\text{C}$ ($55 \text{ }^\circ\text{F}$) at a distance of 60.1 m (200 ft) down from the soil surface. This is the depth of the water table in the tank farm location.

3.2.3 Parameters

This section describes the parameters used in the analysis.

3.2.3.1 Range of Waste Conductivities. Extensive evaluation of the thermal conductivity of tank waste has been conducted by computer analysis. These evaluations have been reported in several documents (McLaren 1993, McLaren

1994a, McLaren 1994b). Laboratory analysis of waste samples has been directed mostly to species identification, with little effort directed toward thermo-hydraulic characteristics. As a result, the range of waste conductivities and their accuracy vary widely. Thermal analysis computer studies of ferrocyanide tanks have yielded thermal conductivity values for saltcake ranging from 0.26 to 1.73 W/m-°C (0.15 to 1.00 Btu/hr-ft-°F). This is a rather extreme range, but includes upper and lower bound analyses. These tanks have been partially stabilized, with most of the free liquid removed from the tanks, consequently the saltcake crusts in these tanks are fairly dry. The range of thermal conductivity for saltcake using nominal case data is from 0.35 to 0.87 W/m-°C (0.20 to 0.50 Btu/hr-ft-°F), with an average of 0.63 W/m-°C (0.36 Btu/hr-ft-°F).

**Figure 1. Typical Noding Diagram for SX-Farm Tanks.
(Dimensions in feet)**

The thermal conductivity of the waste is influenced greatly by its moisture content. Thermal analysis computer studies have yielded values from 0.52 to 2.94 W/m-°C (0.30 to 1.70 Btu/hr-ft-°F). Once again, these are lower to upper bound values. Nominal case values range from 0.78 to 1.73 W/m-°C (0.45 to 1.00 Btu/hr-ft-°F), with an average of 1.17 W/m-°C (0.68 Btu/hr-ft-°F).

The SX-farm tanks on the Flammable Gas Watchlist contain mostly saltcake. These tanks have not had all free liquid removed, and so the saltcake is considered to be wet. The pictures of the waste surface shows that these tanks have some free liquid on the surface. The value of thermal conductivity used for the SX-farm heat load calculations was 1.04 W/m-°C (0.60 Btu/hr-ft-°F). This value was derived from Maxwell's equation for conductivity of a mixture composed of small spheres of one substance dispersed in another, with a volume fraction of 30 percent.

3.2.3.2 Soil Conductivities. Little data exist for the thermal conductivity of the soil in the tank farms. Some analytical work was done by D. G. Bouse (Bouse 1975), but the results were not well documented, specifically in the areas of density used for the thermal conductivity experiments. The results have been considered suspect. During the initial stages of construction of the Multi-Waste Treatment Facility, soil samples were obtained in the areas where the storage tanks were planned to be placed. These samples were sent to Geoscience Ltd, of Solana Beach, California, and various analyses were conducted and documented (Poppendiek, et al. 1993). The results of these analyses were used in the heat load analyses of the SX-farm tanks.

The thermal conductivity of the soil surrounding the tanks is dependent upon the moisture in the soil. Moisture monitoring of the soil has been accomplished, and the data from a typical well are shown in Figure 2.

These data indicate that down to about 12 m (40 ft) the soil moisture is about 4 percent. Below 12 m the moisture drops to 2 percent. The soil around the tank in the model was divided into two regions, shallow and deep. These regions, with their moisture values, are shown in Figure 3. The thermal conductivities assigned to these regions are temperature dependent functions taken from Poppendiek's report and are tabulated in Table 1.

Figure 2. Soil Moisture Profiles in Well 32-49D.

Figure 3. Soil Regions in Tank Model.

Table 1. Nominal Soil Conductivity Values (Btu/hr-ft-°F).

Soil Regions	Moisture (wt %)	Thermal Conductivity (W/m-°C / Btu/hr-ft-°F)		
		13 °C / 55 °F	43 °C / 110 °F	77 °C 170 °F
Shallow	4	0.93 / 0.537	0.95 / 0.547	0.99 / 0.57
Deep	2	0.69 / 0.400	0.71 / 0.412	0.74 / 0.43
Deep	2	1.02 / 0.59	1.06 / 0.61	1.09 / 0.63

3.2.3.3 Data. The data used to estimate the heat load of a tank consisted of temperatures at various depths within the waste and vapor space. These temperatures were obtained from thermocouple trees with from 6 to 8 thermocouples on them. Unfortunately, in over half the tanks studied insufficient data were available to conduct a positive analysis. The data provided for tank 241-SX-105 required estimations to use, and tanks 241-SX-103, -106, and 109 provided data that was marginally useful at best.

Tank 241-SX-103 had four thermocouple readings within the waste at known locations at depths from 0.1 m to 2.5 m (0.34 ft to 8.30 ft) . No temperatures between 2.5 m and the waste surface at 9.3 m (30.55 ft) or in the vapor space were available. Extrapolation provided too much uncertainty, so no analysis was used to estimate the ventilation airflow through this tank. Instead, an approximation, based on observation of airflows from other tanks was used.

Tank 241-SX-105 had thermocouple readings in the waste and vapor space, but no location data. An assumption was made that these thermocouples were in the same location as on the tree in tank 241-SX-104, and the analysis was conducted using these data.

Tank 241-SX-106 had six thermocouple readings but no location data. When the thermocouples were assumed to be at the same locations as on the tree in tank 241-SX-104, an apparent convective layer within the waste was noted. However, the shape of the curve from thermocouple #5 to the surface (the temperature at the surface is assumed to be that of the vapor space) was sloped in the wrong direction. This caused sufficient problems that an analysis of the evaporative heat losses in this tank could not be made. Accordingly, an estimate of the ventilation airflow was made in the same manner as tank 241-SX-103.

The data for tank 241-SX-109 lacked knowledge of the locations of the thermocouples on the tree. In addition, there was apparently no thermocouple reading in the vapor space, which was considered odd as there is only 2.4 m (8 ft) of waste in this tank. The lowest temperature noted in the data was ca. 50 °C (122 °F), which is considered much too high, as the other tanks vapor space data indicate a temperature of 32 °C (50 °F). Some psychrometric data from 1993 exists, which show outlet temperatures ranging from 30 °C to 38 °C (86 °F to 100 °F). Consequently, an outlet temperature of 30 °C was assumed for the ventilation analysis.

3.2.4 Analysis of Tank 241-SX-104

The analysis of the tank's evaporation and convection heat losses starts with the temperature data obtained for the waste and vapor space in the tank. The data used are from January 1 to May 29, 1995. These data are consistent as shown in Figure 4.

Figure 4. Tank 241-SX-104 Temperature Data - Riser #2.

The data for May 8, 1995, were used as the benchmark for the analysis. A thermal conductivity of $1.04 \text{ W/m}\cdot^\circ\text{C}$ ($0.60 \text{ Btu/hr}\cdot\text{ft}\cdot^\circ\text{F}$) was used for the waste. A total heat load of 4.4 kW ($15,000 \text{ Btu/hr}$) with no evaporation or convection loss was selected for the first attempt. The shape of the data curves indicate that the heat load is not homogeneously distributed. A distribution of all of the heat in the lower 2.4 m (8 ft) was assumed, based on the shape of the data curve. The results of this first attempt showed that the thermal conductivity assumed was not too high, as the predicted curve showed a steeper slope than the data. The next attempt utilized a heat load of 5.3 kW ($18,000 \text{ Btu/hr}$), with no evaporative or convective heat losses. The results of this attempt predicted higher temperatures than the data curve. Then assumptions of evaporative and convective heat losses were input and the predictions compared to the data until a fairly good match between the predictions and the data was obtained. This occurred with a total heat load of 5.3 kW with a 1.3 kW ($18,000$ and 4400 Btu/hr) evaporative and convective heat loss. These results are shown in Figure 5.

The evaporative and convective heat loss of 1.3 kW is then input into the lumped parameter GOTHIC model to solve for the ventilation airflow for the tank.

Figure 5. Tank 214-SX-104 Computer Predictions versus Data
Temperature versus Height.

3.3 SX-FARM MODEL

The Flammable Gas Watchlist tanks in the SX-Farm are: 241-SX-101, -102, -103, -104, -105, -106, and -109. These tanks are actively ventilated by an exhaust fan that draws atmospheric air into each tank. Tanks SX-101 through -106 are ventilated in parallel, into a common exhaust duct that empties into tank SX-109. This tank discharges through the ventilation fan located in the exhaust duct of this tank. Consequently, while tanks SX-101 through -106 are in parallel with each other, tank SX-109 is in series with that group. The first six of these tanks generate hydrogen and release it into the tank gas space periodically. The seventh tank, SX-109 does not generate hydrogen, but, by being in series with the other six, will have a hydrogen content when one of the other tanks experiences a gas release event.

The model of the SX-farm is shown in Figure 6. Each of the seven tanks on the Flammable Gas Watchlist is individually modeled as is the ventilation ducting connecting them. Each tank takes suction from a boundary volume that describes the atmosphere and SX-109 exhausts to an atmospheric boundary volume. While there are eight separate boundary volumes their descriptions are identical. The boundary conditions are shown in Table 2. Each tank has a heater in it. This heater represents the heat lost from the tank due to evaporation and convective cooling. The heater is placed so to heat the liquid in the tank. Each tank model uses a liquid pool of 10 percent of the surface area of the waste with a liquid content of the tank of 1 percent of the total volume. The initial temperature of the tank vapor space and liquid is the airspace temperature determined by the temperature data. The ventilation airflow is determined by specifying the volumetric flow rate through a volumetric fan, placed on the outlet duct from tank SX-109.

Figure 6. Noding Diagram of GOTHIC SX-Farm Model.

Table 2. Atmospheric Boundary Conditions.

Temperature (°C / °F)		Water vapor pressure ratio
Dry Bulb	Wet Bulb	
12.2 / 54	8.9 / 48	0.0059

The model is run by specifying the initial temperature for both the liquid pool and the airspace, and the heater power for the heat lost to evaporation and convection. An airflow is chosen and specified for the

volumetric fan, and the problem run for an extended period of time, normally $1.0E+6$ seconds. This length of time is needed because the problem develops a slow transient that takes about $5.0E+5$ seconds to settle out. The time history of the vapor space temperature is observed, and the initial and final temperatures are compared. The ventilation flow is adjusted until the vapor space temperature shows no rapid or large oscillations and the initial and final temperatures are equal or nearly so ($\epsilon < 0.5$ °C). At this point, the ventilation airflow can be considered to be correct for the conditions specified. As all but tank SX-109 are in parallel with each other, they can be solved individually. Tank SX-109 must be solved with the other tanks in the system.

The tank farm model was altered to solve for tank SX-109 ventilation airflow by putting a volumetric fan on the outlet of each tank, with the previously determined flow for each tank through each fan. This locked in the ventilation airflows upstream of tank SX-109. Then the thermodynamic conditions in the duct just upstream of tank SX-109 and the airflow out of that duct were noted. A small model was created, consisting of tank SX-109, the atmospheric boundary volumes for inlet air and discharge receiver, and a boundary volume with the thermodynamic conditions previously noted, connected with associated ducting, and a volumetric fan on the tank SX-109 discharge duct. This model was created to reduce the running time of the computer simulation. The connection between the boundary volume representing the other six tanks in parallel and tank SX-109 was a constant flow boundary. In this way, the proper inlet airflow and exhaust flows could be determined without having to constantly adjust flow parameters upstream in the ventilation ducting. The solution of this model provided the inlet ventilation airflow for tank SX-109 and the total flow through the ventilation exhaust fan. With the ventilation airflows known, a three-dimensional model of each tank in the complex can be created and analyzed.

3.4 TANK 3-DIMENSIONAL VAPOR SPACE MODEL

3.4.1 Evaluation Using Classical Jet Theory

The ventilation air stream that enters each SX tank forms a jet which can be evaluated based on classical jet theory. For a submerged turbulent jet, the centerline species concentration decreases with distance from the inlet nozzle as shown below (Blevins 1984).

$$\Delta T_m = 10 (r_o/x) \Delta T_o \quad (1)$$

where:

- ΔT_m = species concentration at the jet centerline
- r_o = nozzle radius
- x = axial distance from the nozzle exit
- ΔT_o = species concentration at the nozzle exit

For the SX tank situation, the concentration of air at the nozzle exit is unity when expressed as a volume fraction. At increasing axial distance from the nozzle exit, entrainment of tank gas by the jet causes the air volume

fraction to decrease and the tank gas volume fraction to increase. The result in terms of tank gas concentration at the jet centerline is shown in Figure 7.

Figure 7. Centerline Concentration Profile for an SX Tank Inlet Ventilation Jet.

The jet centerline contains the lowest concentration of entrained gasses, consequently any displacement of the detector from the centerline will improve the ability of the detector to measure that bulk gas concentration. The minimum distance from inlet riser to the detector location for the SX farm watch list tanks is about 2.4 m (7.9 ft). Given this dimension, examination of Figure 7 shows that the expected concentration of tank gas at the detector location is at least 80% of the bulk value. This means that if the tank atmosphere contained hydrogen at a concentration of 1 percent by volume, the detector near the waste surface could be expected to read 0.8 percent. Therefore, based on this evaluation the proposed detector location below the ventilation air inlet riser appears to be satisfactory.

3.4.2 GOTHIC Model

The results presented above represent the steady-state behavior of a submerged turbulent jet entering a quiescent reservoir containing the same fluid as the jet. They do not account for any density differences between the inlet air and the tank gas, nor do they include the effect that buoyancy driven flows caused by temperature differences within the tank may have on the inlet air stream. A crossflow component in the jetflow will deflect the jetflow, displacing the detector position more towards the side of the jet, and increasing the tank gas concentration in the vicinity of the detector. Consequently the detector would measure a higher percentage of the bulk gas concentration. The classical jet theory results also fail to address any transient behavior that would occur during a tank gas release event. To

address these questions, a three-dimensional GOTHIC model was constructed for the SX tanks. The GOTHIC model nodalization is shown in Figures 8 and 9.

Figure 8. GOTHIC Model Nodalization - Elevation View.

Figure 9. GOTHIC Model Nodalization - Plan View.

Mesh spacing in the vertical direction decreases from 1.5 m (5 ft) at the bottom of the tank air space to 0.6 m (2 ft) at the top. Horizontal mesh spacing is 1.5 m except in the channels near the ventilation inlet, where the

minimum dimension is 0.6 m. The shaded regions in Figures 7 and 8 represent null cells, which were specified to approximate the curved tank walls and dome.

The above mesh dimensions provide a reasonable amount of detail throughout the tank while limiting the required computer resources to a practical level. However, they do not contain sufficient detail in the region of the jet inlet to provide an accurate calculation of jet spreading and entrainment. To overcome this problem, the jet was modeled by placing a momentum source at the axial location where the jet would expand to fill the smallest mesh cell. That axial location and the total flow rate of the momentum source, including entrainment, were calculated using jet theory. With the momentum source thus specified, it is expected that the GOTHIC model should provide a reasonable calculation of jet spreading beyond that point.

4.0 RESULTS

4.1 SX-FARM MODEL

4.1.1 Results of Conduction Model

The conduction model was used to estimate the heat loss from the tanks due to evaporation and convection. The total heat load of the tank was also estimated. As a result of the lack of data, these parameters for tanks 241-SX-103, -105, -106, and -109 could only be approximated. These parameters estimated from the analysis of the Flammable Gas Watchlist tanks in the SX-farm using the conduction model are summarized in Table 3.

**Table 3. Results of Conduction Model Analyses of SX-farm
Flammable Gas Watchlist Tanks.**

Tank Number	Heat Load (kW / Btu/hr)	Evaporative and convective heat load (kW/ Btu/hr)	Thermal conductivity of waste (W/m-°C / Btu/hr-ft-°F)
241-SX-101	5.57 / 19,000	1.26 / 4300	0.61 / 0.35
241-SX-102	5.86 / 20,000	1.35 / 4600	1.04 / 0.60
241-SX-103	Not estimated	1.25 / 4250	1.04 / 0.60
241-SX-104	5.28 / 18000	1.36 / 4650	1.04 / 0.60
241-Sx-105	5.72 / 19,500	0.97 / 3300	1.04 / 0.60
241-SX-106	Not estimated	0.97 / 3300	1.04 / 0.60
241-SX-109	Not estimated	0.35 / 1200	Not used

4.1.2 Results of GOTHIC Farm Model

The results of the analysis of the GOTHIC model of the SX-farm are shown in table 4. The heat load and vapor space temperature for tank 241-SX-109 had to be approximated as the available data were not able to support an analysis to estimate these parameters.

Table 4. Results of GOTHIC SX-Farm Model Analysis of SX-farm Flammable Gas Watchlist Tanks.

Tank number	Ventilation airflow (m ³ /min / ft ³ /min)	Evaporative and convective heat load (kW / Btu/hr)	Tank airspace temperature (°C / °F)
241-SX-101	0.78 (27.5 cfm)	1.26 / 4300	32.8 / 91.
241-SX-102	0.83 (29.3 cfm)	1.35 / 4600	32.2 / 90.
241-SX-103	0.81 (28.6 cfm)	1.25 / 4250	32.2 / 90.
241-SX-104	1.03 (36.4 cfm)	1.36 / 4650	29.1 / 84.
241-SX-105	0.61 (21.5 cfm)	0.97 / 3300	32.8 / 90.
241-SX-106	0.81 (28.6 cfm)	0.97 / 3300	27.8 / 82.
241-SX-109	0.63 (22.2 cfm)	0.35 / 1200	30.0 / 86.

4.2 GAS SPACE MIXING ANALYSES

The GOTHIC model was used to evaluate three different cases for the SX tanks: (1) a uniform temperature case, (2) a case where the waste surface temperature was 1 °C (2 °F) higher than the walls and dome, and (3) a case with elevated waste surface temperature and a gas release in the tank. For each of the above cases, the ventilation flow rate was set to 0.99 m³/min (35 cfm).

4.2.1 Probe Evaluation Under Steady-State Conditions

Case 1 was a uniform temperature case with tank walls, dome, and the waste surface all at the same temperature. The GOTHIC results were compared to jet theory calculations at those points beyond the model momentum source. The results are presented in Table 5. The jet theory results are for an average value for a channel size equal to the GOTHIC model center channel. Consequently the results are higher than the values presented in Figure 7, which presents values only at the jet centerline.

The above comparison indicates that the GOTHIC model slightly over predicts the jet spreading, which is reasonable given the coarse mesh. In terms of a hydrogen detector located 5.2 m (17 ft) from the bottom of the ventilation inlet riser, these results indicate that while jet theory would

predict the detector should read approximately 90 percent of the bulk concentration (Figure 7), the GOTHIC model would predict that it should read 95 percent.

Table 5. Comparison of GOTHIC Results and Jet Theory.

Axial distance (m / ft)	Average fraction of tank air in the jet center channel	
	Jet theory	GOTHIC model
2.0 / 6.65	0.866	0.933
3.4 / 11.15	0.883	0.948
4.9 / 16.15	0.908	0.953

Steady-state velocity vectors for case 1 are shown in Figure 10. The most notable observation from this figure is that the ventilation jet has very little effect on the atmosphere in bulk of the tank. Except in the immediate vicinity of the jet, gas velocities appear to be less than 0.03 m/s (0.1 ft/sec).

The analysis of case 1, Figure 11, shows the effect of increasing the waste surface temperature by 1 °C (2 °F). In this case, buoyancy driven flows are significant and appear strong enough to actually deflect the jet. This situation is probably more realistic than case 1 for the SX tanks because of the decay heat source in the waste material. The fact that convection flows appear strong enough to deflect the jet is favorable in terms of hydrogen detector location because it means the detector will not be located on the jet centerline. The entrainment by a jet in crossflow is about an order of magnitude larger than that in the jet in a stagnant fluid (Rajaratnum, 1976). Therefore, any hydrogen concentration the detector measures should be even closer to the actual bulk tank concentration than predicted by the jet theory evaluation.

Figure 10. Velocity Vectors for Uniform Temperature Case.

Velocity Vectors in Vertical Planes

Back

Middle

Front

$\vec{V}_{\max} = 1 \text{ (ft/s)}$

Figure 11. Velocity Vectors for Elevated Waste Temperature Case.

Velocity Vectors in Vertical Planes

The position of the hydrogen detector probe within the tanks of interest is given in the Table 6. ECN 608113 indicates that the detectors were placed at the end of probes whose lengths are listed in column 2 of the table. The radial position of the riser the probe was inserted into is shown in column 3. The detector position below the tank riser bottom was calculated with a centerline depth of soil over the tank of 2.4 m (8 feet), 0.4 m (1.25 ft) of concrete in the tank dome, and assuming the riser penetrates 0.3 m (1 ft) into the tank. This position is shown in column 4. The hydrogen detector for tank 241-SX-109 is located in the exhaust duct, not in the tank.

Table 6. Hydrogen Detector Position.

Tank number	Probe length	Radius to riser	Detector length below riser bottom
241-SX-101	23.8 m (26 ft)	11.9 m (13 ft)	4.5 m (14.7 ft)
241-SX-102	22.0 m (24 ft)	12.8 m (14 ft)	3.9 m (12.7 ft)
241-SX-103	22.0 m (24 ft)	27.4 m (30 ft)	2.4 m (7.9 ft)
241-SX-104	22.0 m (24 ft)	27.4 m (30 ft)	2.4 m (7.9 ft)
241-SX-105	22.0 m (24 ft)	27.4 m (30 ft)	2.4 m (7.9 ft)
241-SX-106	23.8 m (26 ft)	28.4 m (31 ft)	3.0 m (9.9 ft)

As a result of the location of the detectors with respect to the bottom of the inlet riser, the hydrogen concentrations in the airstream measured by the probes will not be that in the tank atmosphere. However, the difference in the concentrations in the airstream seen by the detector and the tank atmosphere will not be more than 20 percent under the worst conditions, as shown in Table 7. The expected fraction values range from undisturbed jet theory centerline values to the GOTHIC predictions with circulation currents in the tank vapor space.

Table 7. Expected Readings from Hydrogen Probes.

Tank number	Detector length below riser bottom	Expected fraction of tank air in sample
241-SX-101	4.5 m (14.7 ft)	0.89 to 0.95
241-SX-102	3.9 m (12.7 ft)	0.83 to 0.95
241-SX-103	2.2 m (7.9 ft)	0.80 to 0.94
241-SX-104	2.2 m (7.9 ft)	0.80 to 0.94
241-SX-105	2.2 m (7.9 ft)	0.80 to 0.94
241-SX-106	3.0 m (9.9 ft)	0.82 to 0.94

4.2.2 Probe Evaluation Under Transient Conditions

A case of a gas release was studied to determine the changes in circulation patterns within the tank. The gas release was 17.0 m^3 in 30 seconds with a hydrogen concentration of 60%. These parameters were obtained from an evaluation of a gas release event in tank AW-101 (McLaren 1994c). Figure 12 shows velocity vectors for this case immediately after the beginning of the gas release, which was spread over a single mesh cell (2.3 m^2) on the opposite side of the tank from the inlet riser. The velocities induced by this release are much stronger than those associated with either the convection flows or the jet itself.

Figure 13 shows hydrogen concentration contours during the gas release. In this figure, the gas can be seen rising to the dome and then spreading out across the tank. Figure 14 shows the hydrogen contours approximately two minutes later. Gas mixing is not yet complete, as indicated by the vertical concentration gradient. There is some distortion of the hydrogen concentration profiles in the vicinity of the jet, but the concentration at the detector locations are not significantly different from any other location in the tank at a similar elevation.

Figure 12. Velocity Vectors during Gas Release Event.

Velocity Vectors in Vertical Planes

Figure 13. Hydrogen Concentration Contours During the Gas Release Event.

Hydrogen Contours in Vertical Planes

Figure 14. Hydrogen Concentration Contours Two Minutes after
the Gas Release Event.

Hydrogen Contours in Vertical Planes

Minimum = 0.00055556 (rel)
Maximum = 0.005 (rel)

5.0 CONCLUSIONS

The analysis shows that the jet of ventilation inlet air does not appreciably perturb the vapor space gas concentrations seen by the hydrogen detectors in the ventilation airstream. The analysis also indicates that the circulation patterns within the vapor space will decrease the hydrogen concentration error between the atmosphere sampled by the hydrogen detector and the bulk atmosphere in the tank.

The analysis of a gas release event in an SX-farm tank shows that the sampling probe will show the increased values of flammable gas within minutes of the release. The analysis also shows that mixing of the released gas with the atmosphere in the tank vapor space occurs rapidly, within minutes.

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