2022 Tank Pressure/Vacuum Pallet Damage: Crude Oil Storage Tank Headspace Gas Assessment

Report Prepared for:

PRINCE WILLIAM SOUND RCAC REGIONAL CITIZENS' ADVISORY COUNCIL

PWSRCAC Contract # 5081.22-01

PREPARED BY:

William Mott P.E.

taku engineering

907.562.1247

December 2024

STATE OF ALASKA 49TH William R. Mott MM-13991 REGISTERED PROFESSIONAL ENGINEER

Table of Contents

ACRONYMS & ABBREVIATIONS

ADEC – Alaska Department of Environmental Conservation

ADOL – Alaska Department of Labor

APSC – Alyeska Pipeline Service Company

BWT – Ballast Water Treatment

ETF – East Tank Farm

FLIR - Forward Looking InfraRed

HP – High Pressure

LP – Low Pressure

MSCFH – Thousand Standard Cubic Feet Per Hour

O_2 – Oxygen

PWSRCAC - Prince William Sound Regional Citizens' Advisory Council

Taku – Taku Engineering, LLC

VMT – Valdez Marine Terminal

1.0 BACKGROUND

1.1 GENERAL

During the winter of 2021-2022, snow accumulated on top of the crude oil tanks located within the East Tank Farm (ETF) at the Valdez Marine Terminal (VMT). Insufficient snow removal efforts caused glaciation of the snowpack on top of the tanks, inflicting damage to many of the pressure/vacuum pallets (also referred to as "vents"). In areas of significant damage, where the vents were completely sheared off due to snow, the tanks operated with open holes that freely released hydrocarbon vapors into the atmosphere.

These pallets are critical infrastructure for safe tank operation. During normal operations, the pallets remain seated and tank headspace pressure is managed with the tank vapor system. In the event of an upset, the pallets are designed alleviate significant tank pressure changes. The pallets allow gas exchange between the inside of the tank and the outside atmosphere, releasing vapors in an over pressurization event or drawing in air in the event of a vacuum, preventing tank structural damage.

Following notification about the pallet damage, several current and former Alyeska employees approached Prince William Sound Regional Citizens' Advisory Council (PWSRCAC) with concerns over safety to personnel and property stemming from the pallet damage and Alyeska's response.

On March 31, 2022, Taku participated in a meeting to discuss the pallet damage and Alyeska Pipeline Service Company's (APSC or Alyeska) response. APSC personnel who attended that meeting included Klint VanWingerden, Brian Huey, Chris Steves, and Weston Branshaw. PWSRCAC staff in attendance were Donna Schantz, Austin Love, and William Mott (Taku Engineering, on behalf of PWSRCAC).

Given Taku Engineering's familiarity with the VMT and tank operations, and our technical background, PWSRCAC requested Taku's assistance with addressing issues raised by concerned employees and Alyeska's overall response. Taku's efforts focused on the assessment of tank headspace conditions during the period of the peak oxygen (O_2) content in the low-pressure vapor header, and Alyeska's interpretations of the tank headspace gas quality during subsequent tank snow clearing efforts.

1.2 INFORMATION PROVIDED BY APSC AT THE MARCH 31, 2022 MEETING

During the March 31, 2022 meeting, APSC provided information on the tank damage and response that had been undertaken to address the damage. The following key points were discussed:

- The hydrocarbon vapor release was discovered through an "olfactory test," which entailed technicians smelling hydrocarbon vapors while doing their rounds. Following the initial discovery, APSC used Forward Looking InfraRed (FLIR) cameras to identify hydrocarbon vapors leaking from damaged pallets on the tanks.
- The crude tanks are normally operated with a slight positive pressure in the headspace. Once significant damage was noted on a tank, the tank vapor system operations was shifted to maintain the headspace under a very slight negative pressure (vacuum) to alleviate hydrocarbon vapor release into the atmosphere.
- Instrumentation for monitoring O_2 content in the vapor system (including the headspace of the tanks) is limited to a single point in the ETF low-pressure header.
- The percent O_2 in the low-pressure header peaked at 5.59% on March 17, 2022, at 12:13 p.m. according to Alyeska's instrumentation for monitoring O_2 content in the vapor system. Alyeska noted

that the system is set to shut down at 8% O_2 and that at its peak, the O_2 concentration in the header as recorded was below the safety shut down point.

- During the March 31 meeting, APSC indicated that 11 of the pallets had been fully sheared from the tanks by the snowpack. Ultimately, Alyeska reported 12 significantly damaged pallets on Tanks 1, 2, 3, 4, 6, 10, 13, and 14. Multiple pallets were significantly damaged on Tank 2 (3 pallets) and Tank 4 (3 pallets).
- During the March 31 meeting, Alyeska indicated that they had used the tank thief hatches to access the headspace of crude tanks to monitor the O_2 concentrations of the tank headspaces to determine if it was safe to put workers on top to clear snow.

1.3 SUMMARY OF CONCERNS

A study of the data and information Alyeska provided to the Alaska Department of Labor (ADOL) and the information provided at the Alyeska-PWSRCAC March 31, 2022 meeting, brought to light several concerns:

- Tank headspace gas mixing is limited to passive flow divertors at the tank vapor inlet and outlet nozzles; this means that gas mixing within the tank is not instantaneous and that the gas mixture in the tank headspace is not homogeneous. As such, when the VMT crude tanks had significantly damaged pallets and were operated at a slight negative pressure (vacuum), air was drawn into the tank at the damaged pallets and the gases in the tank headspaces contained areas with different proportions of flammable gases. The exact size and location of those flammable regions is dependent on several parameters including: the magnitude of the tank vent damage, the level of the negative pressure (vacuum), the age of the crude in the tank (the amount of remaining light ends off gassing), and the degree of mixing in the tank.
- In the March 31, 2022 meeting, Alyeska indicated that the peak O_2 content in the low-pressure header (5.59%) was well below the safety actionable setpoint of 8% and therefore not a concern. However, the low-pressure header is a blend, or an "average" of headspace gases from 16 tanks (15 tanks at the time of the incident as Tank 94 was out of service). A **slight increase in the O_2 content of the header could represent a major O_2 excursion in one or more tanks**.
- Alyeska indicated that they were using the thief hatches as the monitoring point to define the O_2 content of each tank headspace to determine if it was safe for personnel to be on top of the tanks for snow clearing. This assumes that the gas quality at a thief hatch represents the vapor quality throughout the headspace. As noted above, crude headspace mixing is limited to passive diverters. The headspace is not homogeneous and testing at a single point should **not** be taken as representative of the entire headspace. Additionally, the thief hatch on the northern tanks (odd numbered tanks) is located very close to the high-pressure nozzle and between the high-pressure nozzle and the closest pallet. Therefore, the quality of the gases at those thief hatches will be very close to the quality of the gases in the high-pressure header, rather than representative of the bulk quality of the tank headspace gases.
- APSC should not solely be using the "olfactory test" to identify vapor leaks. The olfactory test relies on a technician's ability to smell crude vapors while conducting rounds. That test is subjective and doesn't account for the variability in the sense of smell from person to person, or the dangers in breathing in hydrocarbon vapors. Fixed hydrocarbon monitoring would provide more objective monitoring and detection when upsets occur.
- The existing fixed O_2 and flow monitoring points in the VMT vapor system are insufficient to allow APSC to understand the quality of the vapor space gases in any individual crude tank.

- APSC has not provided all of the available information on the flowrates and quality of each of the vapor streams in the VMT vapor system during the period of the greatest O_2 excursion in the low-pressure header. Without all of the pertinent data from the system, numerous assumptions must be made in order to estimate the average O_2 content in the headspaces of each of the 14 ETF crude tanks. Additional data, as requested from Alyeska in 2022 by PWSRCAC, would improve the accuracy of the gas quality estimates. Taku can update this study and report if APSC provides the requested data.

2.0 DETAILED DISCUSSION OF CONCERNS

From an analysis of the information provided, Alyeska does not have sufficient instrumentation and monitoring equipment to accurately define what is occurring in each tank headspace. As such, Alyeska's report that the peak O_2 content in the low-pressure header was 5.59% during this upset, is not indicative of safe tank headspace gas quality nor does it provide an accurate representation of the true O_2 content within the headspace of any individual tank. The analysis below details the process for arriving at this conclusion, including a discussion of gas testing locations and gas mixing within the headspace.

Alyeska indicated that the tanks are normally operated under a slight pressure. As depicted below, when a tank pallet is sheared off a tank operating at a slight pressure, the headspace is open to the atmosphere and hydrocarbon vapors migrate out of the tank resulting in fugitive emissions. These fugitive emissions are what Alyeska's technicians detected in their "olfactory test." When there is a leak and the tank is operating at a slight pressure, there will be a flammable region (depicted as yellow in Figure 1, below) in the emissions cloud. The size and magnitude of the flammable region will vary and be impacted by the leak rate, temperature, and outside wind speed.

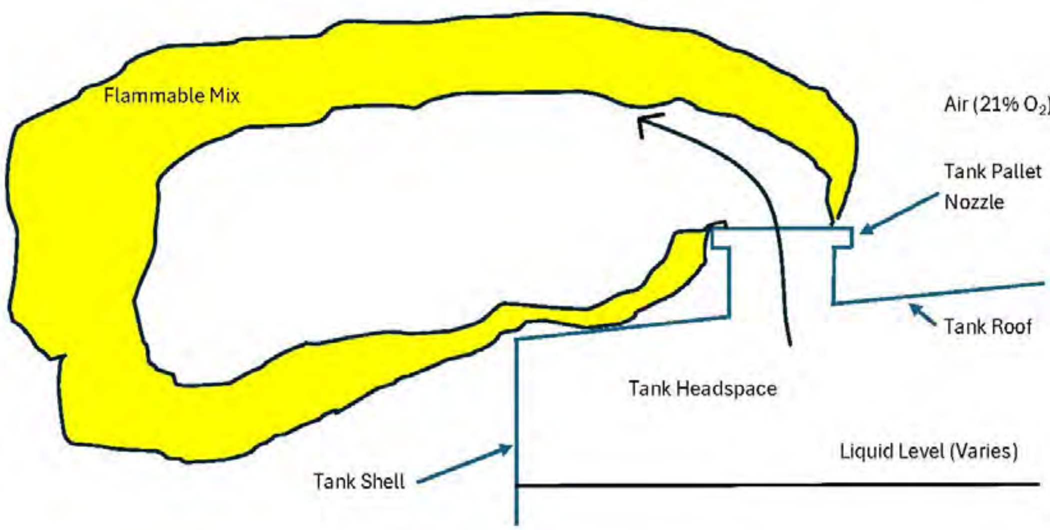

Figure 1 - Tank Emissions at Sheared Pallet (Operating under positive pressure)

Alyeska noted that when leaking pallets were discovered on a subject tank, the operating mode for that tank was shifted to operate with the headspace under a slight negative pressure (vacuum) to limit the release of hydrocarbon vapors to the atmosphere. Whenever there is a significant tank leak and the tank headspace is under a slight vacuum, the air migrating into the tank will create zones where the O_2 concentration is high enough for a flammable/explosive mixture to exist (depicted as yellow in Figure 2 below). Again, this is due to air moving into the tank and the fact that the current mechanisms for headspace gas mixing do not result in a homogeneous gaseous mixture. The size and magnitude of that flammable region will be impacted by the leak rate, temperature, the amount of mixing in the headspace, the volume and age of the oil in the tank, and the magnitude of the operating negative pressure (vacuum). A significant leak in a single tank will also increase the bulk average O_2 content of that tank headspace.

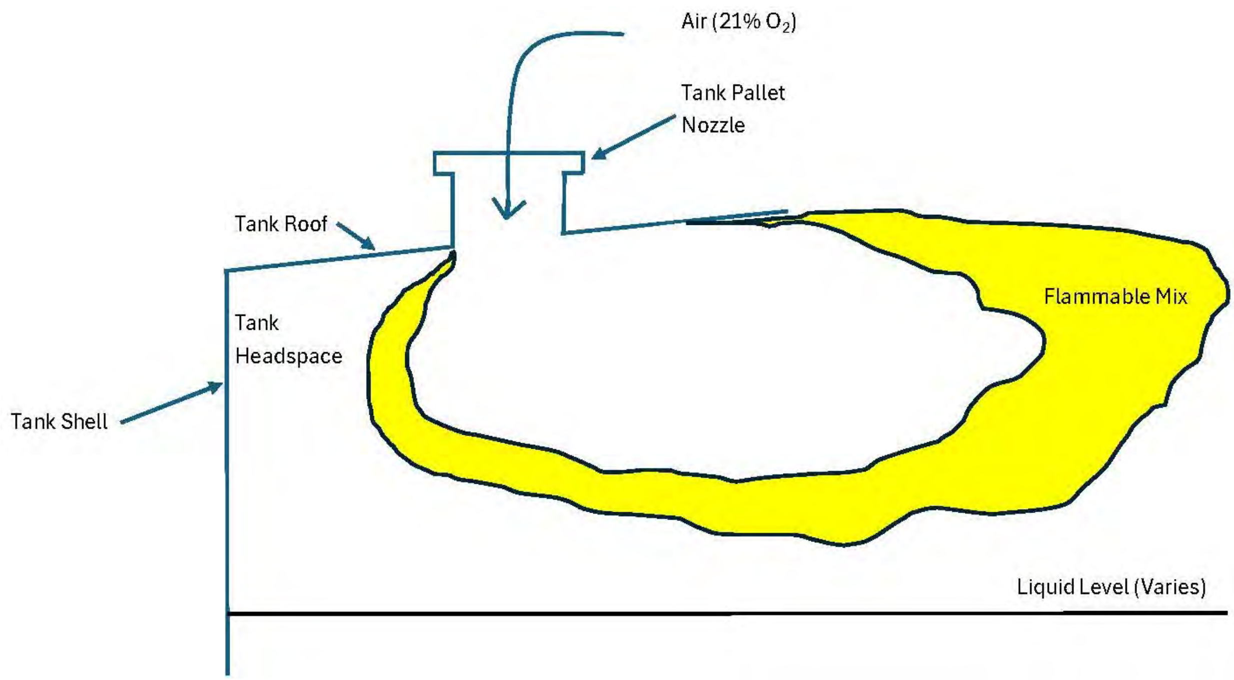

Figure 2 – Air Migration into a Sheared Pallet (Operating under negative pressure - vacuum)

The quality of gas mixing in the crude tank headspace has been a concern for Alyeska for many years. In the past, the close proximity of the high- and low-pressure header nozzles caused the gas flow in the headspace to "short circuit" as the gases move directly between the two nozzles rather than mix in the tank headspace, thus causing ineffective headspace vapor mixing. In early 2000, in recognition of these concerns, and to improve mixing and better mining of the headspace gases, Alyeska retrofitted gas diverters into some of the high- and low-pressure vapor nozzles. It is not known how many of the tanks have diverters installed or how much mixing energy is imparted by the diverters. However, given the size of the tanks, the tank headspaces cannot be assumed to be homogeneous, even with these diverters in place.

During the March 31, 2022 meeting, Alyeska reported that they used the tank thief hatches to sample headspace gases to determine if the tank headspaces were safe to put workers on top of the tanks for snow clearing. Reliance on testing at the thief hatches as the primary means of defining the headspace gas quality was imprudent as the thief hatches on the odd numbered tanks are located close to the high-pressure header between the high-pressure header and the closest pressure/vacuum pallets. That means that the quality of the gases at the thief hatched on the odd numbered tanks will closely mirror the quality of the high-pressure header, not the bulk tank headspace.

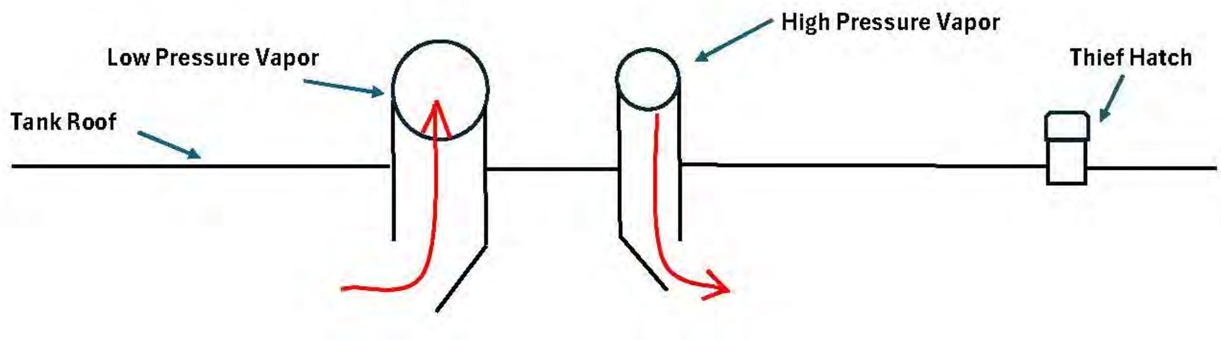

Figure 3 – Vapor Nozzle/Thief Hatch Proximities for Odd Numbered Crude Tanks

Figure 3 presents a basic sketch showing the inert (high pressure or inert) nozzle, the vent (low pressure outlet) nozzle, and the thief hatch for the seven northern ETF tanks (odd # tanks). As seen from this visual representation, based on the tank vapor nozzle locations, the orientation of the vapor diverters (if installed on a given tank), and the relative location of the thief hatch, gas readings at the thief hatch will be similar to the quality of the high-pressure header gases entering the tank rather than representing the average or bulk quality of the tank headspace.

The southern (even numbered tanks) are configured in a slightly different manner. The thief hatches are located very close to the low-pressure (vent) nozzle between the pallets and the low-pressure vapor nozzle. The quality of the gases at the thief hatches on the even numbered tanks is more likely to represent the gas quality in the tank vent header. However, it will not provide any indication of localized areas of flammable gases in the vicinity of the damaged pallets (in tanks operating at a slight vacuum).

During Feb/March 2022 upset, it is probable that any gas measurements that APSC collected at the thief hatches to define the headspace gas quality may have significantly underestimated the amount of oxygen in the tank headspaces. Conclusions drawn from those measurements likely caused Alyeska to underestimate the risk associated tank-top work and to miscommunicate the safety risks to tank farm workers.

Figure 4 shows the roof of Crude Oil Storage Tank 11, depicting the locations of the inlet and outlet nozzles, the thief hatch, the pressure vacuum pallets, and the vapor flow direction that would be expected if vapor diverters were installed (red arrows). In this configuration, as seen visually in the diagram, the headspace gases at the thief hatch will be similar to the quality of the high pressure (inert) gas than the bulk of average quality of the tank headspace. Gas testing collected at thief hatches on the northern tanks (odd # tanks) is very unlikely to include O_2 that enters the tank through damaged pressure vacuum pallets.

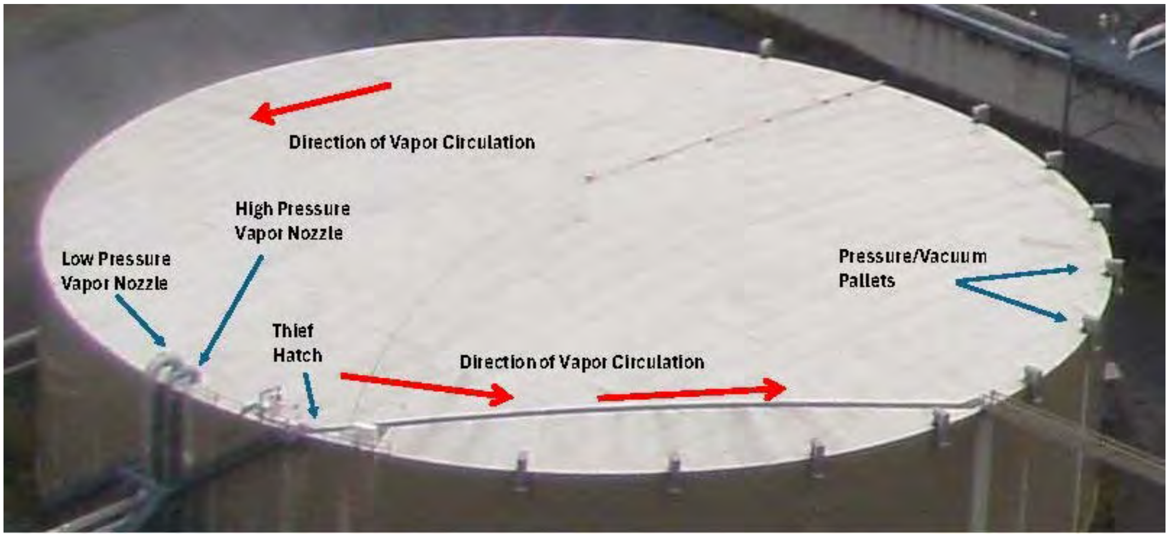

Figure 4 – Tank 11 Roof Appurtenances

3.0 DETAILED HEADSPACE ASSESSMENT

3.1 JUSTIFICATION FOR ASSESSMENT

The data that Alyeska collected at the thief hatches during the pressure vacuum pallet damage incident, did not represent the average bulk gas quality of the tank headspace and did not consider local flammable vapor areas that existed at significantly damaged pallets (in tanks operating at a slight vacuum). Likewise, the limited gas quality data available from fixed instrumentation in the vapor system represents a mixed average quality for all tanks and does not represent the gas quality in any individual tanks.

A comprehensive post-incident assessment should include consideration of all hazards that were present during the incident. The post incident investigation should define those hazards and determine if they were accurately communicated to the workers clearing the tanks. Further, a detailed post-incident assessment should include the development of the processes and instrumentation necessary to alleviate future similar risks to the greatest extent possible.

PWSRCAC has requested the post-incident investigation reports from APSC, which have not been provided to date. However, the communications between PWSRCAC and Alyeska suggest that Alyeska believes that they have fully defined the risks associated with the incident without assessing the flammability of the headspace gases during the incident.

The intent of this assessment was to utilize the data provided to the ADOL to better identify the conditions and risks associated with the tank vent damage. This assessment includes both an assessment of the likelihood of localized areas of flammable gas as well as an estimate of the average flammability of each of the crude tank headspaces during the peak O_2 excursion in the low-pressure header.

Alyeska does not have sufficient instrumentation and monitoring equipment to accurately define what is occurring in each tank headspace. The equipment that they have in place to measure flowrate and O_2 concentration data is limited to a single point in the East Tank Farm. They should have the capability to measure the flow and quality of the gases from each tank. Without that information, they cannot define the risks to their workers and cannot define what specific actions are necessary to operate each tank safely during a system upset.

Without additional data that APSC may have on hand, Taku was forced to make several assumptions to bridge data gaps caused by either the withholding of key data, or the lack of data due to insufficient instrumentation. It is probable that Alyeska has data that could be used in lieu of some of these assumptions. That additional information could be used to refine this assessment and better define the risks that were incurred during the plant upset.

3.2 ASSUMPTIONS AND DATA

Key Assumptions

When making assumptions for this assessment, the assumptions were in a conservative manner and should not be viewed as a worse-case scenario. The following assumptions are based on the time that the oxygen content of the Low-Pressure Header peaked (3/17/2022, 12:13 p.m.):

- There was no flow in the balancing line between the High- and Low-Pressure Headers.
- There was no flow in line from Berth 4 separator (normally closed).
- There was no flow in the Compressor Recycle Line.
- Pallets with little to no damage were not leaking measurably.
- Tanks operating under a slight positive pressure at the time of the peak O_2 concentrations in the low-pressure header were not leaking O_2 into the vapor system.
- Oxygen flowing into the tanks operating at a slight pressure passed though the tank to the low-pressure nozzle and did not vent through the damaged pallets.
- Several tanks were operating at null pressure. This assessment assumed that the O_2 ingress at those tanks was similar to that of the tanks operating at a slight vacuum. This is a conservative approach as the tanks operating at a slight vacuum would logically be allowing more O_2 into the tank through each damaged pallet.
- Ballast Water Treatment (BWT) Tank 94 was not connected to the vapor system (out of service for repairs).
- The contents of the high pressure (HP) and low pressure (LP) headers were well mixed and relatively homogeneous at the locations of the existing monitors.
- This assessment assumes steady state operations for the purpose of estimating the quality of the tank headspace gases – data provided to Taku indicated that there were no major changes to the operating pressure (or vacuum) of any of the tanks in the hours preceding the incident.
- The flowrates in and out of Tank 93 were assumed to be approximately $1/15^{th}$ of the total high- and low-pressure vapor flow to and from the tanks. The calculations were run varying the assumed fraction of the vapor flowrates (from $1/30^{th}$ to $1/7^{th}$) of the total vapor flowrates. These changes did not significantly change the findings resulting from the model.
- Crude vapor flammability starts at about 10% O_2. This value is impacted by several other parameters. However, anything less than 10% O_2 was considered non-flammable for the purpose of this study. Anything greater than 10% O_2 was considered potentially flammable.
- Air was leaking into significantly damaged pallets at a uniform rate per damaged pallet (for tanks not operating at a positive pressure).

Key Data

The following key data was provided to the ADOL regarding conditions at 3/17/2022, 12:13 p.m., and was used as a basis for this analysis:

- Low Pressure Header O_2 Content: 5.57% (two readings, 5.55% & 5.59%. Avg 5.57%).
- BWT Low Pressure Vapor Header O_2 Content: 3.51% (two readings, 3.537% & 3.491%. Avg 3.51%).
- High Pressure Header O_2 Content: 4.45% (two readings, 4.436% & 4.61%. Avg 4.45%).
- Scrubber Outlet O_2 Content: 4.82%.
- Flue Gas Scrubber Flowrate: 126.0 MSCFH.
- Low Pressure Header Flowrate: 641.8 MSCFH.
- Ultimately, 12 significantly damaged pallets were discovered on Tanks 1, 2, 3, 4, 6, 10, 13, and 14. Damaged vents that were reported to have been blinded or plugged prior to 3/17/22 were assumed not to be contributing to the tank headspace oxygen content. Tanks 1 and 3 were reported to have been operating at a slight pressure during the excursion on 3/17. The damaged pallets on Tanks 1 and 3 were assumed not to be contributing to the elevated O_2 in the system at the time of peak O_2 concentration in the header.

3.3 LOW PRESSURE HEADER FLOWRATE CALCULATIONS

The flowrate into the compressors (641.8 MSCFH) is the sum of the flow from the LP header and the flue gas scrubber flow (126.0 MSCFH).

Therefore:

The LP Header flowrate from the ETF & BWT = 641.8 MSCFH – 126.0 MSCFH = 515.8 MSCFH

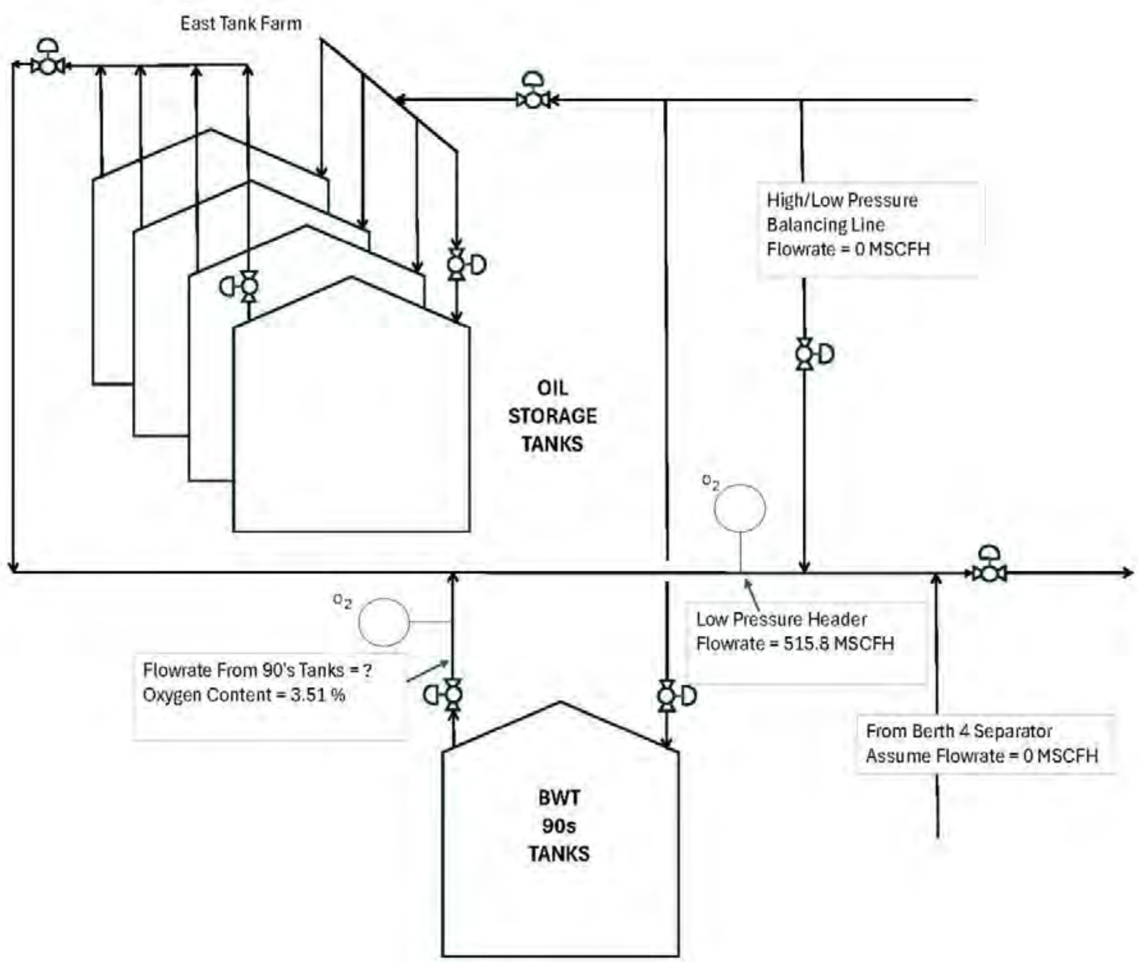

Figure 5 – LP Header Flow Diagram

3.4 BWT TANK 93 FLOWRATE CALCULATIONS

We can assume that the volume of oxygen into Tank 93 is the same as the volume of oxygen out of the tank. Further, during the incident, the vapor system was handling the vapor for 15 tanks. An initial assumption was made that 1/15th of the total low pressure header flow originated from Tank 93 (this assumption was tested by varying the fraction of the LP flow from Tank 93 from 1/7th of the total flow to 1/30th of the total flow, the nature of the findings did not measurably change).

From Section 3.3, the overall flow in the LP header from Tank 93 and the ETF crude tanks was approximately 515.8 MSCFH. Based on the assumption above, the LP gas flowrate from Tank 93 was 515.8/15 or 34.33 MSCFH.

We also know from the data provided that the O_2 content in the BWT LP header was 3.51%. We can assume that the HP O_2 flowrate into Tank 93 is equal to the LP O_2 flowrate out of Tank 93. Therefore, the O_2 flowrate out of Tank 93 was approximately 3.51% * 34.33 MSCFH ≈ 1.2 MSCFH.

The HP vapors going into Tank 93 originate from the HP header. The O_2 content in the HP header was 4.45%. Therefore, the O_2 content of the HP vapors going into Tank 93 was 4.45%. Using the O_2 flowrate into Tank 93 and the % O_2 flowing into Tank 93, we can estimate the HP vapor flowrate into Tank 93.

% O_2 in Tank 93 HP header ≈ (HP O_2 Flowrate into Tank 93/ HP Vapor Flowrate into Tank 93)*100, rearranging

HP Vapor Flowrate into Tank 93 ≈ O_2 flowrate into Tank 93/the % O_2 in the HP Header

≈ (1.2 MSCFH / 4.45%) * 100 ≈ 27.1 MSCFH

Again, assuming that the HP vapor flow to the BWT tanks is 1/15th of the total flow, then the HP vapor flowrate into the ETF crude tanks was:

HP Vapor flow to ETF Crude Tanks ≈ 14* 27.1 MSCFH ≈ 379 MSCFH

O_2 Flowrate in the HP Header ≈ 379 MSCFH * 4.45% ≈ 16.9 MSCFH

3.5 ETF CRUDE TANK VAPOR FLOWRATE ESTIMATIONS

The LP vapor flow from the ETF crude tanks is approximately the difference between the total tank LP vapor flow and the LP vapor flow from Tank 93, or:

LP vapor flow from ETF crude tanks ≈ 515.0 MSCFH - 34.33 MSCFH ≈ 480.7 MSCFH

The total O_2 flowrate from all crude tanks and from the BWT tank can be used to calculate the % O_2 from the ETF tanks by subtracting the O_2 flowrate through Tank 93, from the total O_2 flowrate from all tanks:

Volumetric O_2 LP Flow from the ETF crude tanks ≈ (5.57% * 515.8 MSCFH) – 1.2 MSCFH ≈ 27.5 MSCFH

The O_2 flowrate in the low-pressure header was the sum of the O_2 flowing in from the high-pressure header, plus the O_2 leaking into the tanks at the damaged pallets. Or:

Volumetric Flowrate of O_2 into the tanks through damaged pallets ≈ 27.5 MSCFH – 16.9 MSCFH ≈ 10.6 MSCFH

Regardless of pallet damage, significant volumes of O_2 would not seep into the tanks that were operating normally with intact pallets and operating under a slight pressure. If a tank had damaged pallets and was operating under a slight pressure, hydrocarbon vapors would migrate out of the tank rather than air migrating in. Two of the tanks with noted pallet damage (Tanks 1 and 3) were operating with their headspaces under pressure on March 17, and would have been leaking hydrocarbon out of the tank rather than allowing air to seep into the headspace. For the purposes of this assessment, we assumed that these tanks were not contributing to the elevated O_2 in the low-pressure header. To maintain a conservative approach to the assessment, we did not attempt to account for the O_2 leaking out of Tanks 1 and 3 at the damaged pallets.

Ultimately, it was determined that there were 12 significantly damaged pressure vacuum pallets on the crude tanks after the snow was removed from the tank roofs. For the sake of this study, any pallets that were reported to have been blinded or plugged prior to 3/17/22 were assumed to not be leaking at the time of the O_2 excursion. There were six pallets located on five different tanks that were identified with significantly damaged but had not yet been repaired by 3/17/22. The assessment assumed that all of the errant O_2 in the system was being introduced through these five pallets. Again, additional information from Alyeska that would allow for improved assumptions was requested nearly 24 months ago but has still not been received.

We assumed that the five significantly damaged pallets each allowed the same volume of O_2 to migrate into the tanks. On that basis, the volume of O_2 ingress at each significantly damaged pallet was approximated by:

10.6 MSCFH/5 pallets ≈ 2.12 MSCFH

We were provided the positions for the vent and inert vapor valves on each tank on March 17 during the O_2 excursion. However, the inert and vent valve positions did not align with the pressure/vacuum operating mode of the ETF tanks. Further attempts to use the vent valve positions to estimate the percentage of vapor flow to each crude tank resulted in obvious errors. Since the vent valve positions did not align with the tank pressure/vacuum operating mode, it is assumed that the vent and inert valve position data was in error, the valve positions were dynamic (being changed frequently) or the tank levels were dynamic.

Since the inert and vent valve position data appeared to have inherent flaws, this study assumed that vapor flowrates into and out of each of the crude tanks were the same. The average O_2 ingress rate through each significantly damaged pallet was then used to calculate the average O_2 content of each crude tank headspace,

A summary of the results of these findings is provided in Appendix A.

4.0 SUMMARY/FINDINGS

4.1 GENERAL

This assessment was undertaken to determine if the headspaces may have been flammable during this period that the tanks had damaged pallets. This study was intended to assess the potential for localized areas of flammable tank headspace gases and to estimate the bulk oxygen levels in the VMT crude tanks at the time of the highest levels of oxygen in the low-pressure header.

In Government Letter No. 50082 (to the ADOL), APSC indicated that the highest level of oxygen measured in the low-pressure header was 5.59% at 12:13 p.m. on March 17, 2022. During the March 31, 2022 meeting, they followed this with a discussion that indicated that this oxygen level was below 8% and was therefore not an actionable level that would trigger their automated Safety System.

Applying this "safe" actionable level across the tank farm only makes sense if one assumes that the gas chemistry in each tank is the same and that there are no localized areas of high O_2 concentrations. That may be a valid assumption during normal operating conditions. However, during abnormal conditions such as those experienced in February and March of 2022, that assumption is invalid and could have resulted in a catastrophic incident.

Alyeska should have proceeded under the understanding that the O_2 concentrations in the tank headspaces varied significantly from tank-to-tank and noted that a slight increase in the O_2 content of the low-pressure header may be indicative of a major excursion in the O_2 content of the headspace in one or more tanks.

A comprehensive post-accident assessment for this incident should define the actual risks that were incurred. That should include an assessment of whether the tank headspaces were flammable during the damage occurrence and ensuing response. If Alyeska provides the information that has been requested, Taku will update this study to ensure that we are accurately representing the tank headspace quality at the time of the incident.

4.2 FINDINGS

- The O_2 levels estimated in this study represent an average concentration in each headspace. That should not be misinterpreted to suggest that the tanks with lower O_2 concentrations were entirely safe. **Because the headspaces are not well mixed, there were areas of combustible gas concentrations in all of the tanks that were operating at a slight vacuum and had major unrepaired pallet damage. Tanks 1, 2, 3, 4, 6, 10, 13, and 14 had major pallet damage during the 2022 incidents.**

- At the time of the highest O_2 content in the low-pressure header, the bulk or average O_2 levels on one or more of the crude tank headspaces were estimated to be within the flammable range.
- Alyeska has not provided sufficient data to calculate the exact headspace concentrations in each tank. The results provided in Appendix A are estimates based on the limited information that Alyeska has provided. If Alyeska provided the additional information requested, more accurate results could be achieved.
- The instrumentation for vapor flowrates and O_2 monitoring in the vapor system (including the headspace of the tanks) is limited and insufficient to allow operators to manage the system in the event of abnormal conditions such as the 2022 pallet damage incident.
- The O_2 concentration in the low-pressure header peaked at 5.59% on March 17, 2022, at 12:13 p.m. Alyeska noted that the system is set to shut down at 8% O_2 and that at its peak, the O_2 concentration in the header was well below that point. This suggests that during the upset, they did not understand that tanks with significantly damaged pallets and operating at a vacuum had areas of flammable gas mixtures in the headspace and that some of the tanks may have had bulk gas qualities that were fully within the flammable range.
- The O_2 monitoring and response system seems to be focused on the safety and protection of the powerplant and vapor management system but not on the safety and protection of the crude tanks.
- Alyeska indicated that they had used the tank thief hatches for access to monitor the headspace of each tank to define the O_2 concentrations of the tank headspaces. The use of a thief hatches to determine the quality of an entire headspace inaccurately depicts the headspace gas quality. In this situation, the use of gas quality measurements collected at thief hatches likely underestimated the O_2 content in the tank headspace and resulted in miscommunicating the job hazards to the tank-top workers.

4.3 OPPORTUNITIES TO IMPROVE THIS STUDY

There are a number of gaps in the data and information provided by Alyeska. In order to proceed with this study, a number of assumptions were made to accommodate for the limited data provided. Alyeska should cooperate with PWSRCAC providing additional information in order to improve this model. The additional data that should be provided includes:

- The BWT header gas flowrates or vapor valve positions for Tank 93.
- Confirmation that the flow in balancing line between the High- and Low-Pressure Headers was 0 or provide the flowrate and gas quality data for that line.
- Confirmation that there was no flow in line from Berth 4 separator (no tank loading).
- Confirmation that there was no flow in Compressor Recycle Line or provide the flowrate and gas quality data for that line.
- Confirmation that instrumentation for monitoring O_2 content in the ETF vapor system (including the headspace of the tanks) is limited to a single point in each ETF header (high and low pressure).
- Clarification of the relationship between the inert/vent valve positions, and the tank headspace operating pressure.

Once this additional data is provided, Taku is willing to revise the assessment to reflect the additional data received.

APPENDIX A

Summary of Estimated Tank Headspace Bulk Oxygen Levels

	Tank #													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
HP Flow Into Tank (MSCFH)	27.1	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3
O_2 into Each Tank thru Inert Line (MSCFH)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
# of Unrepaired Significantly Damaged Pallets	1	1	0	2	0	0	0	0	0	1	0	0	1	0
Operating Mode	Press	Vac	Press	Vac	Null	Null	Null	Null	Press	Vac	Vac	Vac	Vac	Vac
# of Significantly Damaged Pallets Leaking O_2 into tank*	0	1	0	2	0	0	0	0	0	1	0	0	1	0
Estimated O_2 into Tank thru Damaged Pallets (MSCFH)	0.00	2.12	0.00	4.24	0.00	0.00	0.00	0.00	0.00	2.12	0.00	0.00	2.12	0.00

Estimated LP Flow from Each Tank (MSCFH)	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3
Estimated Total O_2 out of Each Tank (MSCFH)	1.21	3.33	1.21	5.45	1.21	1.21	1.21	1.21	1.21	3.33	1.21	1.21	3.33	1.21
Estimated Bulk Percent of O_2 out of Each Tank	3.5%	9.7%	3.5%	15.9%	3.5%	3.5%	3.5%	3.5%	3.5%	9.7%	3.5%	3.5%	9.7%	3.5%

* On 3/17/22