noble energy

Consent Decree (90-5-2-1-10811) – 1:15-cv-00841 RBJ

End of Phase Report for Tank Systems with Actual Uncontrolled Annual VOC Emissions of 50 TPY or more

December 2, 2015

Table of Contents

Introduction and Purpose

Consistent with the requirements of Paragraph 59 of the Consent Decree ("CD") between the United States, the State of Colorado, and Noble Energy, Inc. ("Noble"), Civil Action No. 1:15-cv-00841-RBJ, entered by the U.S. District Court for the District of Colorado as final judgment on June 2, 2015, Noble has prepared this End of Phase Report ("End of Phase Report") for Tank Systems[1] that had, as of September 2014, actual uncontrolled annual volatile organic compound ("VOC") emissions of 50 tons per year ("TPY") or more with an Engineering Evaluation deadline of May 1, 2015. Pursuant to Paragraph 10 of the CD, an Engineering Evaluation is the process of applying an appropriate Engineering Design Standard[2] to determine if the existing Vapor Control System[3] at each Tank System is adequately designed and sized to handle the Potential Peak Instantaneous Vapor Flow Rate ("PPIVFR").[4] The Consent Decree requires an End of Phase Report after the Engineering Evaluation deadline for each group of Tank Systems to provide a public summary of useful information gleaned from Engineering Evaluations, and any modifications to improve capture and control achieved by Vapor Control Systems.

Noble's oil and natural gas production operations in the Denver-Julesburg ("D-J") Basin include the use of Condensate[5] tanks. Condensate tanks have the potential to produce vapors from

---

[1] Pursuant to Section III of the CD, "Tank System" shall mean one or more tanks that store Condensate and share a common Vapor Control System.

[2] Pursuant to Section III of the CD, "Engineering Design Standard" shall mean an engineering standard developed by Noble pursuant to Paragraph 9 (Engineering Design Standard).

[3] Pursuant to Section III of the CD, "Vapor Control System" shall mean the system used to contain, convey, and control vapors from Condensate (including flashing, working, breathing, and standing losses, as well as any unintentional gas carry-through to Condensate tanks) at a Tank System. A Vapor Control System includes a Tank System, piping to convey vapors from a Tank System to a combustion device and/or vapor recovery unit, fittings, connectors, liquid knockout vessels or vapor control piping, openings on Condensate tanks (such as pressure relief valves ("PRVs") and thief hatches), and emission control devices.

[4] Pursuant to Section III of the CD, "Potential Peak Instantaneous Vapor Flow Rate" shall mean the maximum instantaneous amount of vapors routed to a Vapor Control System during Normal Operations (defined as all periods of operation, excluding Malfunctions, and explicitly including, for storage tanks at well production facilities, liquid dumps from the Separator), including flashing, working, breathing, and standing losses, as determined using the Modeling Guideline (defined as the modeling guideline developed by Noble pursuant to Paragraph 8 (Development of a Modeling Guideline)).

[5] Pursuant to Section III of the CD, "Condensate" shall mean hydrocarbon liquids that remain liquid at standard conditions (68 degrees Fahrenheit and 29.92 inches mercury) and are formed by condensation from, or produced with, natural gas, and which have an American Petroleum Institute gravity ("API gravity") of 40 degrees or greater.

flashing and working and breathing losses. Flashing occurs when Condensate or produced water is dumped from pressurized two-phase and three-phase Separators[6] into storage tanks, at or near atmospheric pressure, causing vapors to be released or "flashed" into a gaseous state as a result of the pressure drop. Working and breathing losses are vapors that may be released from Condensate due to liquid level changes and temperature fluctuations. Noble's operations also include the use of produced water storage tanks that may also produce vapors from flashing and working and breathing losses. While produced water storage tanks are not directly subject to the CD, the emissions are considered by the Engineering Evaluations when they are connected to a Tank System's Vapor Control System.

Vapor Control Systems are installed on Noble Tank Systems to route vapors from a Tank System to an emission control device. Where flashing, breathing, and/or working emissions have the potential to exceed Vapor Control System capacity, Vapor Control System modifications are necessary to ensure proper capture and control of emissions.

For purposes of the Tank Systems covered by this End of Phase Report, Noble did not create a general Engineering Design Standard for use at multiple Tank Systems. Rather, Noble used a site-specific Engineering Design Standard to ensure a Vapor Control System was designed and adequately sized for the PPIVFR of the Tank System. This End of Phase Report covers the 83 Tanks Systems with actual uncontrolled annual VOC emissions of 50 TPY or more as of September 2014.

This End of Phase Report is divided into five (5) sections that, based on the best currently available information, address the following:

- Section 1: An overview of the Engineering Design Standard considerations identified in Paragraph 9 of the CD;
- Section 2: A discussion of requirements, constraints, and limitations of operation and/or design parameters for the Tank Systems and Vapor Control Systems;
- Section 3: A summary of design and implementation challenges;
- Section 4: A summary of Vapor Control Systems operations; and
- Section 5: A discussion of any other significant observations associated with the Tank Systems and Vapor Control Systems.

---

[6] Pursuant to Section III of the CD, "Separator" shall mean a pressurized vessel used for separating a well stream into gaseous and liquid components.

1. Engineering Design Standard Overview

Pursuant to Paragraph 9 of the CD, "Noble shall complete Engineering Design Standards to provide sufficient guidance to design adequately sized and properly functioning Vapor Control Systems at the Tank Systems in each of the Three Line Pressure Groupings[7] or any subset of such grouping as Noble may determine appropriate (including individual Tank Systems)."

During this reporting period, Noble did not develop a Three Line Pressure Grouping or subset grouping Engineering Design Standard for the Tank Systems. Instead, Noble developed individual site-specific Engineering Design Standards for those Tank Systems covered during this reporting period.

In developing individual site-specific Engineering Design Standards, Noble collected existing Tank System and Vapor Control System data, evaluated designing and sizing options for Vapor Control System piping and components, and ultimately selected equipment to control Tank System vapors (e.g., Separators and emission control devices). The site-specific Engineering Design Standards were then evaluated against existing field conditions to determine whether and to what extent to modify Vapor Control Systems.

1.1 Vapor Control Technologies

Vapor Control System technologies considered by Noble included: (1) staged separation and constraints on Separator operation (e.g., pressure and liquid dump rates as discussed in Section 1.4); (2) number and volume of storage tanks; (3) tank-to-combustor piping (as discussed Section 1.3); and (4) properly sized emission control devices, including combustors.

Staged separation is used to reduce the pressure of liquids dumped to Condensate tanks and thereby reduce potential flashing losses. Two-stage systems employ a high-pressure ("HP") Separator operated above the sales gas line pressure and a low-pressure ("LP") Separator that receives liquids from the first stage. The LP Separator generally operates below the sales gas line pressure. Vapors produced in the LP Separator are piped to a dedicated combustor and the LP Separator liquids are dumped to a storage tank. A third separation stage, typically a vapor recovery tower ("VRT"), is used at some sites to further reduce the Separator pressure and

---

[7] Pursuant to Section III of the CD, "Three Line Pressure Groupings" shall initially mean the distribution of Tank Systems that are associated with Well Production Operations (defined as surface operations to produce Condensate and natural gas from a well but not including maintenance activities (e.g., swabbing)) which produce gas into sales lines, that, as of August 17, 2014, had line pressures within the following three ranges: (1) 233 psi or greater ("Group I"); (2) less than 233 psi and greater than or equal to 186 psi ("Group II"); and (3) less than 186 psi ("Group III").

associated potential flashing rate. Gas generated in the VRT is recovered for sales or piped to a dedicated combustor(s).

The number of Condensate storage tanks and the volume of Condensate within the storage tanks dictate the volume of headspace available to accumulate gas pressure during a Separator dump. The headspace also contributes to breathing losses. Increased headspace is subject to thermal expansion; therefore, as the volume of headspace increases the amount of breathing losses also increase.

Maximum vapor flowrates to the combustor are estimated and combustors are sized using manufacturer specifications (i.e., vapor flow rate vs. combustor inlet pressure curves) with appropriate adjustments for vapor density (e.g., adjust for elevation, vapor specific gravity). An independent evaluation of burner capacities conducted by Noble supported the burner manufacturer specifications. Ancillary equipment (e.g., flame arrestor, knock out vessel) pressure losses are included in the tank-to-combustor pipeline design as discussed in Section 1.3.

1.2 Site-specific Construction Constraints

Vapor Control System construction or modification can be constrained by numerous site-specific constraints including, but not limited to, footprint limitations, setbacks, and maximum equipment count.

The addition of equipment to a facility may increase the overall surface footprint of the site. Depending on the site, surface footprint limitations may exist outside of Noble's control, such as local or state setback requirements, existing agreements, and/or adjacent public rights-of-way (e.g., roadways). During the time period covered by this reporting period, the most common surface footprint increase resulted from the installation of above-ground vapor capture lines between a Tank System and an emission control device.

Associated with surface footprint expansions, the time needed to finalize revisions to existing agreements governing Noble operations is another site-specific construction constraint encountered during Vapor Control System construction or modification. In many instances, Noble was required to consult with agreement holders to receive approval for the proposed expansions.

1.3 Tank-to-combustor piping system design considerations

The design of the piping system between the Tank System and the combustor(s) considers the vapor flowrate and pressure drop allowance, which are affected by: (1) the pipeline diameter and length (including sections of differing diameter), and components (e.g., elbows, valves, flame arrestors); (2) the vapor combustor pressure drop (i.e., combustor inlet pressure vs. gas flowrate correlation); (3) the initial (i.e., pre-Separator dump) tank headspace gas pressure; and (4) the vapor density (i.e., specific gravity, temperature, and pressure).

For storage tanks with a pressure relief valve manufacturer recommended set point of 16 oz/in^2, the piping is conservatively designed by Noble to result in a typical maximum tank pressure of less than 10 oz/in^2 and an absolute maximum tank pressure of 11 oz/in^2. This constraint results in a 20% contingency capacity that is inherent to Noble's Vapor Control System design. The vapor specific gravity is assumed to be near the maximum of values determined from analysis of representative pressurized Separator liquid samples and associated HYSYS flash simulations. The vapor flowrate is based on conservative estimates of flash gas generation rates and working and breathing losses. The flash gas generation rate used in the steady-state and transient models discussed below is calculated by available industry correlations (e.g., Valko-McCain Method) as well as the Separator liquid dump characteristics discussed in Section 1.4. Working and breathing losses are conservatively estimated from industry standard guidance (e.g., API Standard 2000). The Spitzglass equation is used to estimate pipeline pressure drop and guide the pipeline design. Equivalent pipeline lengths for components are based on standard engineering texts and guidelines (e.g., Crane Valves North America Technical Paper 410).

A transient model is used instead of a steady-state model because it is infeasible to design a Vapor Control System to manage steady-state PPIVFR. The transient model is more applicable because PPIVFR is a very dynamic, short-duration event. The transient model considers the storage tanks' headspace capacity and is used to evaluate tank-to-combustor piping system and Vapor Control System design capacities. The model's PPIVFR is simulated by dumping all Separators simultaneously. The transient analysis steps through increments of time and reevaluates:

- Vapor flowing into the headspace of the tanks (i.e., flash gas, breathing losses, and working losses);
- Liquid height in all tanks (determines working losses and available headspace);
- Pressure rise in tank; and
- Vapor flow exiting the tanks to the combustors.

The tank pressure at the conclusion of the Separator(s) dump is compared to the 10 oz/in^2 design pressure limit to determine if the Vapor Control System capacity is sufficient.

The transient model is used to evaluate the baseline Vapor Control Systems as configured at the time of the evaluation, as well as potential modification options.

1.4 Separator liquid dump characteristics

The Tank Systems and associated Vapor Control Systems covered by this reporting period have a wide range of well and Separator configurations that include, but are not limited to: (1) two-stage and three-stage separation; (2) single and multiple wells feeding a HP Separator; (3) single and multiple HP Separators feeding a LP Separator; (4) single and multiple LP Separators feeding a VRT; and (5) single and multiple LP Separators feeding a Tank System.

The site-specific Engineering Design Standard simulation for determining Separator dump characteristics generally assumes the operating conditions that would result in the maximum possible Separator liquid dump and flash gas generation rates. Primary considerations include:

- A determination that separator-to-tank liquid dump rates (e.g., gal/min) primarily depend on the Separator pressure, liquid characteristics, and dump valve parameters;
  - For Vapor Control System design purposes, HP Separator maximum operating pressure is typically based on the pipeline rupture pin pressure or 25 psi less than the Separator nameplate pressure (i.e., the set point for the shut-in controller on the Hi/Lo valve);
  - Maximum LP Separator design operating pressure is determined by the Engineering Evaluation process and additional shut-in controls are installed to enforce that pressure limit, which is typically 50 to 70 psig. Condensate characteristics are conservatively based on API gravities between 76 to 92, which increase the modeled Separator dump rate and flash gas generation rate; and
  - The dump valve characteristics (i.e., valve coefficients Cv and Cf) are based on manufacturer specifications.
- Analysis of one year of well production data to determine appropriate oil, water, and gas production rates for modeling.
  - Conservatively high production rates are selected.
- Analysis of well automation data to determine appropriate well cycle frequencies and durations for modeling simulations.
  - Conservatively high production rates are selected.

- Development of additional considerations specific to HP Separator liquid dumps for Tank Systems with multiple wells feeding a common HP Separator with intermittent flow (*e.g.*, due to discrete well cycling events), which include:
  - Implementing process engineering controls that eliminate the ability for multiple wells with a common Separator to cycle simultaneously;
  - Combining production rate and well cycle data to ensure conservative estimates as model inputs;
  - Establishing the total volume of liquid (oil or water) dumped per valve cycle based on Separator manufacturer data and using this volume and the dump valve flowrate (discussed above) to calculate the associated duration of these individual dump events.
  - Calculating the time between dump events and the number of dump events associated with a well cycle based on the well cycle duration, well cycle production volume, and Separator dump duration and volume; and
  - Assuming simultaneous Separator dumps (both oil and water dumps) where multiple HP Separators dump to a Tank System.
- Development of additional considerations specific to LP Separator liquid dumps for Tank Systems with multiple HP Separators feeding a common LP Separator with intermittent flow, which include:
  - Combining production rate and well cycle data to ensure conservative estimates as model inputs;
  - Basing well cycle duration on the average for all associated wells;
  - Calculating the total volume of liquid (oil or water) dumped per valve cycle based on Separator manufacturer data and using this volume and the dump valve flowrate (discussed above) to calculate the associated duration of these individual dump events;
  - Calculating the time between dump events and the number of dump events associated with a well cycle based on the well cycle duration, well cycle production volume, and Separator dump duration and volume; and
  - Assuming simultaneous Separator dumps (both oil and water dumps) where multiple LP Separators dump to a Tank System.
- A determination that for Tank Systems receiving Condensate from a VRT, the VRT is essentially a surge vessel and the Condensate flow to the tanks will approach a continuous rate during well production cycles.
  - However, a conservative approach is used to model Vapor Control Systems with a VRT whereby the same modeling used for LP Separator systems is used with one change; the

flash gas generation rate is based on the VRT Engineering Design Standard pressure (12 psig).

1.5 Storage tank headspace

The available headspace in the storage tank(s) is conservatively assumed to be the minimum, which is established as the volume of headspace above the tank liquid level at the equalizing height. This equalizing height depends on the tank volume and dimensions, and is typically 90-95% of the tank height. For example, a typical 300 bbl tank's straight-side height is 15 feet and the centerline of the equalizing line is at 14 feet. Factoring in the cone roof volume, this results in a minimum headspace volume of 168 ft^3 (or 30 bbl, 10% of nameplate tank volume) when liquid level is at the bottom of the equalizing line.

1.6 Other Vapor Control System design considerations

During the development of site-specific Vapor Control System Engineering Design Standards, Noble investigated other issues and parameters that are generally difficult to accurately quantify such as fouling, potential for liquids accumulation in lines, winter operations, and data variability. Because the impacts associated with these issues and parameters are difficult to quantify, the Vapor Control Systems were conservatively "over designed" (e.g., based on worst-case temperatures, pressures, flowrates, etc.) to accommodate unexpected gas flows and restrictions. To ensure at least 20% contingency in the designs, the maximum allowable tank pressure is 11 oz/in^2. All PRVs and thief hatches on the storage tanks have a set point of 16 oz/in^2 before pressure would be relieved through those openings. Liquids accumulation in pipelines is avoided by installing sloped above-ground lines with periodic liquid knockouts.

2. Requirements, Constraints, and Limitations of Operation and/or Design Parameters

Site-specific Vapor Control System design and operating requirements, constraints, and limitations may include:

- Above-ground tank-to-combustor vapor pipelines to preclude condensation settling at a low point and blocking flow;
- HP Separator maximum operating pressure limited by either (1) the pipeline rupture pin or emergency shutdown pressure or (2) 25 psi less than the Separator rated pressure, with Hi/Lo valve controller shut-in of wells if this separator shutdown pressure is exceeded;
- For Tank Systems with two-stage separation, maximum/design LP Separator operating pressure is determined by the Engineering Evaluation process with a dedicated Hi/Lo valve controller to shut-in wells and enforce that pressure limit;

- Installation of additional combustors to ensure sufficient capacity;
- Removal of unnecessary storage tanks at a Tank System to eliminate unnecessary breathing losses;
- Separator dump valve trim size (i.e., valve coefficients Cv and Cf) for Condensate and produced water dumps to control the flowrates of liquids to the tanks;
- Well-head automation to prevent simultaneous production into different Separators associated with a Tank System and associated flash gas generation;
- For Tank Systems that include a VRT, the maximum/design operating VRT pressure is determined by the VRT emergency shutdown pressure, and all oil must flow through the VRT to control the flash potential of the oil when it enters a storage tank; and
- Storage tank liquid level limited to Vapor Control System design height by automation (e.g., high level shut-down) to ensure sufficient tank vapor headspace.

3. Summary of Design or Implementation Challenges Encountered

One design challenge of note and one implementation challenge of note were encountered for Tank Systems and Vapor Control Systems evaluated during this reporting period.

Design Challenge:
Increased well pad footprint required to install above-ground tank-to-combustor vent gas pipelines.

The site-specific Engineering Design Standards include replacing all underground tank-to-combustor vent gas pipelines with above-ground lines to preclude gas condensation and flow obstruction. The above-ground lines sometimes required modifying the driveway/turnaround pathway for tanker trucks, and a larger well pad footprint to accommodate the driveway modifications. At select well pads, negotiations associated with increased footprint requirements were an implementation challenge.

Implementation Challenge:
Well shut-in caused by low-pressure Separator pressure spikes during large production cycles.

As noted in Section 1, two-stage separation was installed to lower the pre-tank Separator pressure and associated Condensate flash gas generation rate. Gas generated in the low-pressure Separator is combusted in a dedicated combustor(s). The LP Separator gas combustor(s) were sized based on historical production rates and volumes, and for the majority of the sites the combustion rate has been sufficient to maintain the LP Separator pressure below the maximum/design operating pressure. However, some Tank Systems experience an occasional larger-than-expected production cycle, which increases the LP Separator gas generation rate such that the combustor could not maintain the LP Separator pressure below the maximum operating pressure, and the Hi/Lo valve controller shut in the well(s) to preclude tank over-pressure. These events did not result in tank venting. In response to these events, the production department is re-optimizing the well production (e.g., by adjusting choke setting and/or well cycle frequency) in consideration of the modified Vapor Control System constraints.

4. Summary of Vapor Control System Operations

A review of available information supports the conclusion that the modified Vapor Control Systems have effectively controlled tank vapors. Pursuant to Paragraph 12.a. of the CD, Noble was required to conduct an IR camera inspection of each Tank System during and immediately after a dump event to confirm the Vapor Control System is adequately designed and not emitting VOCs. IR camera verifications and operator reports for the modified Tank Systems covered by this reporting period did not observe gas venting from storage tank PRVs or thief hatches. Accordingly, there are no corrective actions to report at this time.

5. Summary of Other Significant Observations

For this reporting period, there were no other significant observations associated with the Tank Systems and Vapor Control Systems.

6. Certification

Pursuant to Paragraph 63 of the Noble Energy Consent Decree, I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

12/3/2015

Mark Patteson

Date

Vice President, DJ Basin Business Unit