Challenges of Retrofitting Upstream Facilities for Tank Venting to Flare

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Abstract

Over the last decade volatile organic compound (VOC) emissions from onshore production pads have come under closer scrutiny with passing of Code of Federal Regulations 40 Part 60 Subpart OOOO and OOOOa (commonly referred to as "Quad O" and "Quad Oa") regulations. Facilities constructed prior to Aug. 23, 2011 are exempt from these regulations unless a well or facility is "modified". Modified facilities with existing tanks expected to emit over 6 tons of VOCs per year fall under the regulation and are therefore required to reduce VOC emissions by 95%. This paper details the process for designing and implementing a tank vent capture system and examines the challenges recently encountered during a retrofit of 50+ existing modified facilities in the Williston Basin. These challenges often include high capital costs for older facilities/wells, limitations of existing equipment, and non-optimized process flow, creating higher potential to emit at tanks. Utilizing the lessons learned from these retrofits can save time and costs on future modified facilities as well as help avoid these issues in the design phase of new facilities.

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Introduction

Existing facilities designed and constructed prior to the implementation of Code of Federal Regulations 40 Part 60 Subpart OOOO and OOOOa [2] were typically designed without considerations for emissions off of tanks. These facilities can later become designated as Quad Oa facilities due to any modifications of the facility. Once these facilities become designated "modified" facilities, operators are faced with the task of retrofitting tank batteries to capture or significantly reduce their emissions rate. The most common emission reduction method is the installation of a vent system that flows to a flare or other type of combustor. Some US states also require a Professional Engineer to certify that the vent capture system is adequately designed for emissions capture [1]. This paper will detail a typical design process for vent capture systems for both new and existing facilities as well as examine a number of common issues encountered during a recent retrofit of 50+ Williston Basin tank batteries.

The two types of control devices that are commonly used to mitigate tank vent emissions are vapor recovery units (VRUs) and combustion devices (flares or combustors). VRUs are compressor units that handle the emissions off tanks to allow the tank gas to be routed to the higher-pressure sales gas system. The most important metric for VRUs is runtime, because any downtime of the compressors means that the tanks will emit gas through their thief hatches or other pressure relief device. Combustion devices can typically operate at or below the maximum operating pressure of tanks. A vent system is required to route the tank vapors to the combustion device and often includes a knockout vessel to handle liquids. Combustion devices ensure a certain destruction efficiency of VOCs in order to meet the requirements of Quad Oa (often 98% or higher) and can be more reliable than VRUs. Many factors go into the decision to utilize a VRU or combustion device for tank emissions, including facility location, gas gathering system capacity, and cost. For the purpose of this paper, we will focus on the challenges associated with implementing a combustion device as the emissions control device.

Methods

Once a tank battery has been identified to need emissions control, the required design rate for the tank vent system can be determined. In order to comply with Quad Oa requirements, systems are designed to prevent any outbreathing during normal operations. API Standard 2000 "*Venting Atmospheric and Low-pressure Storage Tanks*"[3] details 3 contributing sources to the overall outbreathing rate for a given tank; displacement, flashing liquids, and thermal. These are considered normal outbreathing and can occur simultaneously, so all 3 must be considered in the design rate of the system. Displacement refers to the rate at which incoming liquid displaces the vapor space of the tank. The incoming liquid rate used to determine this rate should be the maximum expected liquid rate entering the tank under normal conditions. This means all sources of liquid upstream are included and any snap-acting level control valves are assumed to be 100% open. API Standard 2000 gives 2 different equations for displacement calculations based on volatile and non-volatile liquids. Volatile liquids generate a higher vapor displacement rate due to the shift in vapor-liquid equilibrium in the tank as a result of the incoming liquids. The equation for volatile liquid displacement rate is given in Equation 1 below.

$$\dot{V}_{OP} = 16.04 * \dot{V}_{pf} \qquad \text{(Equation 1)}$$

Where,

$\dot{V}_{pf}$ *is the maximum volumetric fill rate of volatile liquid (gpm)*
$\dot{V}_{OP}$ *is the maximum volumetric vapor displacement rate (acfh)*

Flashing liquids can contribute a significant amount to the required outbreathing of a tank when the fluid entering has a higher vapor pressure than the tank operating pressure. Typically, a flash gas factor, which is defined by volume of gas per volume of liquid (i.e. scf/bbl), will be determined from process modeling of the overall facility and specific fluid composition. This flash gas factor is then multiplied by the same maximum liquid rate entering used for displacement to determine the maximum outbreathing contribution from flashing liquids.

Thermal effects on tanks is the final contribution to normal outbreathing. Thermal outbreathing occurs when the surface of a tank cycles from cool to warm due to normal atmospheric changes causing expansion of the vapor inside. This rate is directly correlated to tank volume. Equation 2 below is the API Standard 2000 equation for thermal outbreathing. It includes a factor for the latitude of the tanks which is detailed in Table 1.It also includes an insulation factor to take credit for any protection from thermal effects. The insulation factor is 1 for any uninsulated tanks and additional equations for determining the insulation factor on insulated tanks can be found in API Standard 2000.

$$\dot{V}_{OT} = 1.51 * \mathrm{Y} * \mathrm{V}_{\mathrm{tk}}^{0.9} * \mathrm{R}_{\mathrm{i}} \qquad \text{(Equation 2)}$$

Where,

Y is a factor for the latitude
V_{tk} *is the tank volume* (ft^3)
R_i *is the insulation factor*
$\dot{V}_{OT}$ *is the maximum vapor displacement rate (acfh)*

Table 1 - Y-Factors for Various Latitudes

Latitude	**Y-Factor**
Below 42	0.32
Between 42 and 58	0.25
Above 58	0.20

The required design rate for the tank vent capture system is the combined rate of these 3 contributing outbreathing rates. Using the design rate, the vent system can be engineered to ensure no emissions occur under normal operating conditions. These calculations only work to determine the normal outbreathing of a tank for emissions control purposes. Emergency venting devices and overpressure protection may require higher design rates due to control valve failure, gas blowby, fire, and other relief scenarios. All overpressure scenarios should still be evaluated on a case-by-case basis.

There are 3 components to a tank vent system; a knockout vessel for any condensing liquids, the pipe routing, and the combustion device. At this point, a location needs to be selected for the combustion device. Locating the device near the tank battery helps minimize piping required and lower the overall pressure drop of the system. However, there are many other considerations that go into combustion device location including spacing requirements from other equipment, wind direction, ground radiation, and safety of personnel. Once a location is selected, a proposed routing can be drafted using simple isometric sketches including a location for a liquid knockout. A continuous slope to the knockout vessel with no pockets is recommended to prevent liquid accumulation in the vent line, which causes increased pressure drop through the system. A commonly-used rule of thumb found in API recommended practice is to use a minimum of ¼” per 10’ to allow proper drainage [4].

The system is then sized to ensure it can handle the design rate required. A maximum allowable backpressure on tanks is set based on either maximum allowable working pressure or the set pressures of relief devices on tanks. Typically, the lowest set pressure device on a tank is the thief hatch. Thief hatches will begin to leak below their set pressure so establishing a design margin for the maximum allowable backpressure is required to ensure all emissions are captured. Frictional losses through the proposed routing and expected fittings can then be evaluated to determine the required line size. The combustion device and flame arrestor may or may not be selected at this point in the design, but it is important to remember to account for the pressure drop through these parts of the system since they usually account for a large portion of the overall pressure drop. Combustion device selection can be based on a number of factors including pressure required, combustion efficiency, exit velocity, and local regulations.

The proposed design for the tank vent capture system can now be submitted for construction. Depending on state regulations, a professional engineer may be required to certify the engineering calculations performed to ensure tank emissions are captured under normal operating conditions. The design process is the same for both new and existing facilities. However, issues are often encountered on existing facility retrofits where a tank vent capture system was not originally planned. Some of the most common challenges for implementing a tank vent capture system encountered on the Williston Basin facilities included existing equipment limitations, site spacing, and lack of capital.

Case Study

This case study is for the retrofit of 50+ existing modified facilities in the Williston Basin and examines the impacts of design decisions on equipment selected before the implementation of Quad Oa. The impact of upstream equipment selection, tank design criteria, and the vent system design will be examined using a number of sites from the retrofits as examples. These challenges all resulted in added time and cost for the design and construction of the tank vent capture systems. Using these retrofits as an example, we can avoid these design constrictions in the future and minimize time, cost, and effort on future builds.

One of the most common challenges encountered on a number of sites was limitations of existing equipment upstream of tanks. The operation of separation vessels play a significant role on tank emissions before oil ever enters the tank. The method of level control and operation of liquid dump valves on separation equipment has an impact on the overall design rate required for the tank vent capture system. The first type of level control in separators is intended to maintain a liquid level set point within the vessel by throttling the liquid level control valve partially opened or closed depending on the liquid fill rate. Throttling control valves, in general, provide a steady flowrate of fluid to the tank equal to the overall facility rate. The second type of level control in separators maintains a liquid level between a high and low set point within the vessel. The liquid level control valve fully opens on a high liquid level signal and fully closes on a low liquid level signal until the liquid level rises again. Snap-acting control valves send an instantaneous liquid flowrate to tanks much higher than the overall incoming liquid rate. The overall volume of liquid sent over a short period of time is usually only a small amount contained in the weir or bucket of the vessel, but it can be enough to generate a high instantaneous rate of tank vapors that need to be handled by the vent system. Control valves on new facilities are typically operated as throttling valves at peak production when the flowrate is close to the design rate for the valves. These valves can often be converted to snap-acting control when production declines past the maximum turndown of the valve depending on the type of level controller being used. This was one of the most common issues we encountered on the modified facilties due to the decline in total production. Typically, the minimum opening for an equal-percentage control valve should be 20% to avoid washing out the valve trim. Since these valves were oversized for the declining facility rate, they could not throttle and maintain a minimum 20% opening. Figure 1 below shows the difference in the two types of level control and the effect it has on the required design rate for tank vapors.

In this instance, a facility producing an average of 1,500 bbl/d of oil is equipped with a snap-acting control valve with a capacity of 6,000 bbl/d. The snap-acting control valve maintains a liquid level between 2ft and 4ft in the weir of an 8’-0” O.D. x 30’-0” S/S horizontal separator and dumps a total of 32 bbl of oil per cycle every 40 minutes approximately. The higher oil flowrate for snap-acting valves contributes to both a higher flash gas and displaced gas rate at tanks. The table below shows the resulting design rate and required vent line size to ensure the backpressure at tanks does not exceed the design pressure of 12 oz/in^2. All lengths and fittings were assumed to be the same in the 2 scenarios. A 6” ventline to flare would be required to maintain a maximum backpressure below the leak point of the thief hatch. If a throttling valve were used, the vent line size would only need to be 3”. The increased rate also resulted in an increased number of flare tips required based on the flare type being used since the flare capacity needs to account for peak vent rate.

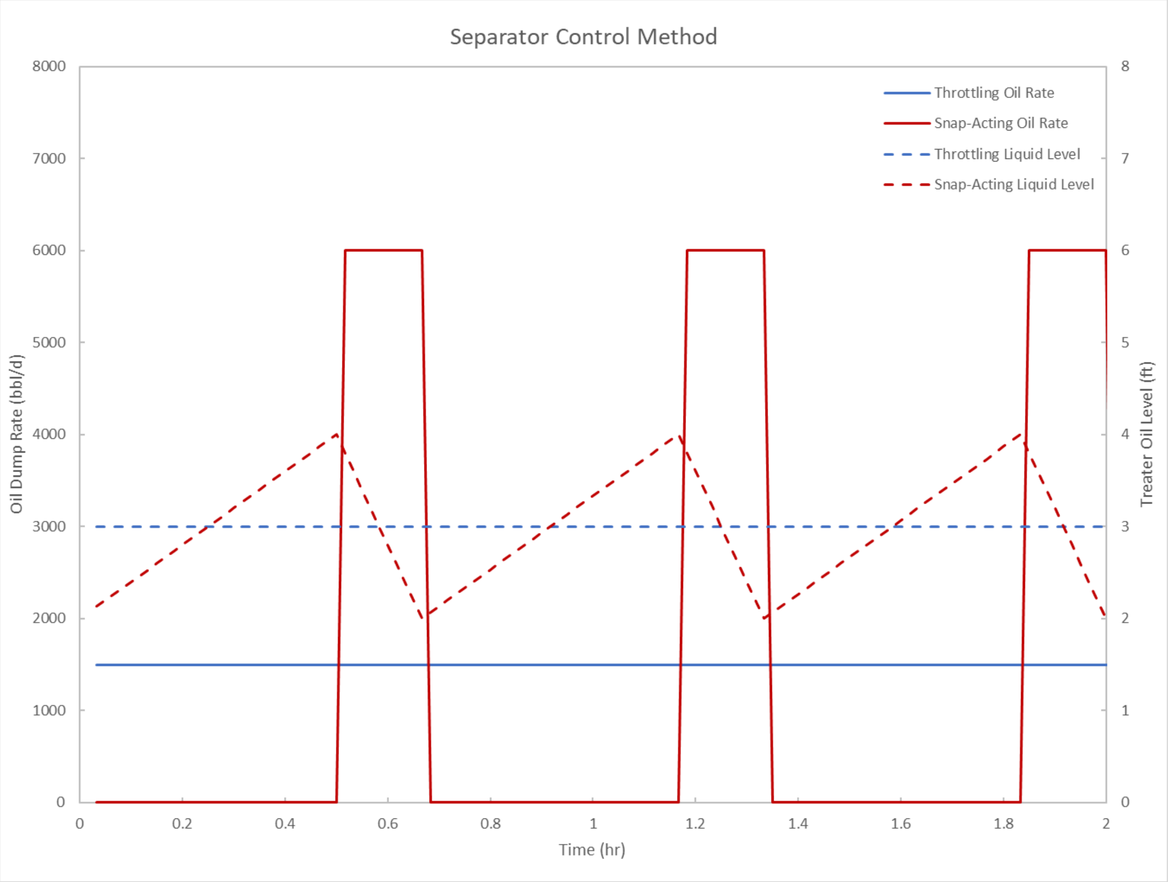

Figure 1 - Comparison of Snap-Acting and Throttling Level Control

The tanks experience long periods with no incoming fluid flow with snap-acting valves. Once a high level is reached in the upstream vessel, the volume of the separator dumps to tanks at a flowrate significantly higher than the incoming facility rate. This can cause the pressure in the tanks to spike suddenly and the vent system must be designed to handle the amount of vapor generated in a shorter period of time.

Table 2 - Comparison of Vent Design for Snap-Acting and Throttling Control

Control Type		Snap-Acting	Throttling
Max Rate to Tanks	(bbl/d)	6,000	1,500
Flash Gas Rate	(Mscfd)	553.4	138.3
Displaced Gas Rate	(Mscfd)	67.4	16.8
Thermal Gas Rate	(Mscfd)	3.9	3.9
Design Rate	(Mscfd)	624.6	159.1
Flare Count		3	1
Flare Pressure Drop	(psi)	3.01	1.73
Required Vent Size		6"	3"
Tank Backpressure	(oz/in2)	6.16	7.53

A number of options were evaluated for minimizing the design rate for the tank vent system for sites that had large snap-acting valves like the one shown above. The first option was to replace the existing control valves with smaller valves that could throttle flow to tanks. This would result in the smallest possible design rate for the tank vent system but required new valves and level controllers to be purchased and installed. When the level control system could be switched to throttling and did not need to be replaced, this option was often cost-saving to replace the valves and minimize the overall vent design rate. The second option was to minimize the flowrate across the existing control valves while still allowing them to operate in snap-acting mode. Two common ways to do this was to install travel stops on the stem of the valves, or to install orifice plates downstream of the valves. Travel stops physically limit the valve from fully opening on high level. This limits the effective Cv value for the valve and results in a lower flowrate. This option is limited to the minimum open percentage of the valve, so it does not work for valves that are significantly oversized. Orifice plates installed downstream of the valve artificially increase the pressure drop through the system, and can be designed for a target flowrate, while allowing the valve to operate normally. This option was used on a number of sites where replacing the valves and control system was too costly. The chart below shows how an orifice plate was used to limit the maximum flowrate to tanks by increasing the cycle time of a single control valve dump. The orifice plate was sized for 120% of the estimated facility flowrate in order to allow for fluctuations in overall facility rate. It is important to include a sizing factor to ensure the orifice is sized for the actual maximum production rate to the facility rather than a daily average to avoid high-leveling the separator vessel during periods of high production.

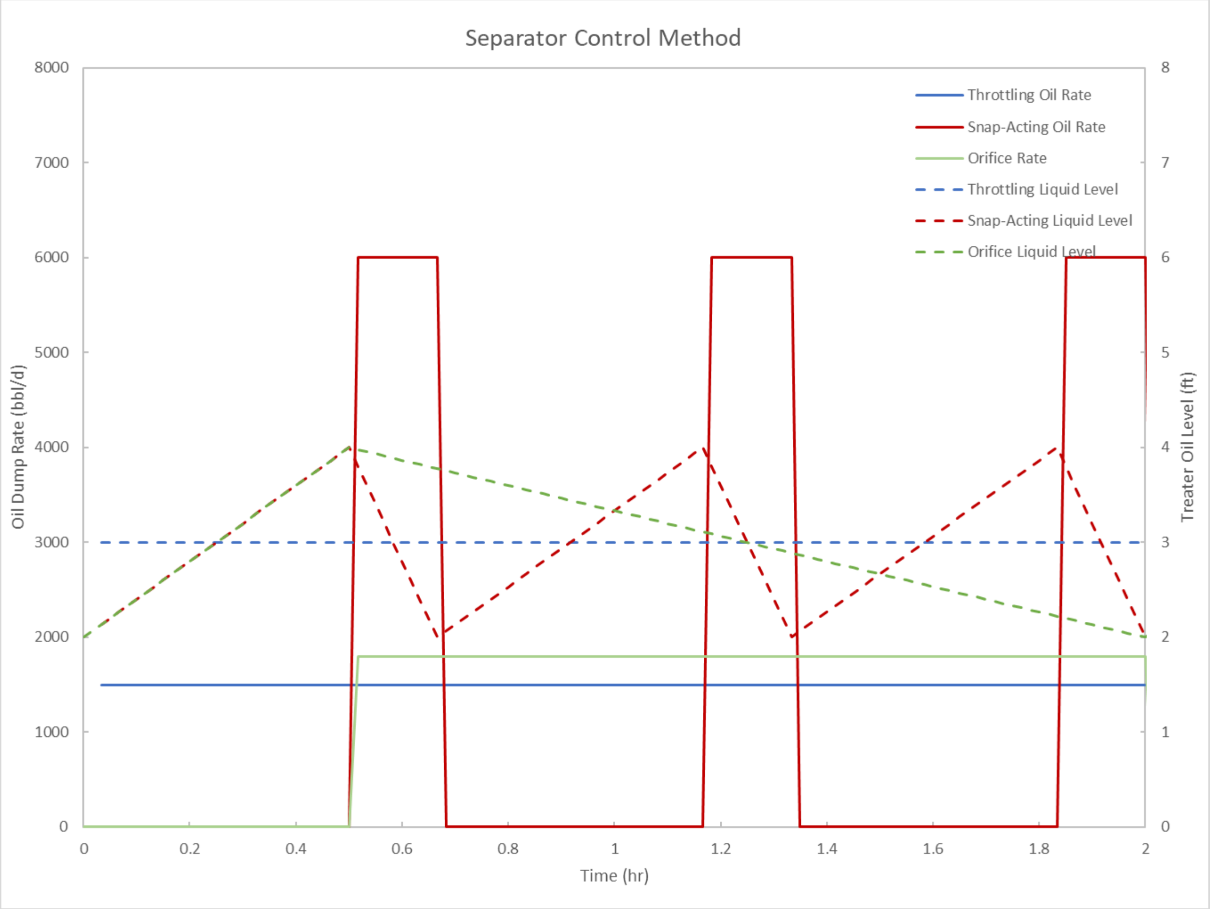

Figure 2: Liquid dump cycle of a snap-acting control valve with orifice plate to restrict flow

The cycle time for the control valve using an orifice downstream was extended from 40 minutes to 2 hours and decreased the peak oil rate to tanks from 6,000 bbl/d to 1,800 bbl/d. This allowed for the 3” ventline to be installed rather than a 6” line for the same site. For new facilities, the vent system will often be designed for peak expected rates using the throttling rate of the control valves. However, the future snap-acting rate may be higher than initial production rates. In order to avoid these issues on future sites, it is useful to plan for interchangeable control valves with removable spool pieces or utilizing 2 50% valves that can be removed from service later.

The design specifications for existing tanks also caused a number of problems with the tank vent design. The maximum allowable working pressures (MAWPs) of the tanks were often lower than current API 12F standards and had inadequate nozzle sizes for the vent connection. Low MAWPs, in the range of 2-4 oz/in^2, require larger vent capture systems to keep within the acceptable pressure drop limits. The table below shows the tank specifications from API Specification 12F Thirteenth Edition.

Table 3 - API 12F Tank Specifications [3]

Nominal Capacity	Dimensions		Design Pressure		Size of Connection
bbl	ft, in.	ft	oz/in2		in
	OD	H	Pressure	Vacuum	Roof Top Vent
90	7, 11	10	16	1	4
100	9, 6	8	16	1	4
150	9, 6	12	16	1	4
200	12	10	16	1	4
210	10	15	16	1	4
250	11	15	16	1	6
300	12	15	16	1	6
400	12	20	16	1	6
500	12	25	16	1	6
500	15, 6	16	16	1	6
750	15, 6	24	16	1	6
1000	15, 6	30	16	1	6

All API 12F tank sizes are required to have a design pressure of 16 oz/in^2 in the latest edition. It also requires a 4” or 6” roof vent connection depending on the nominal capacity of the tank. Existing tanks often were built to other specifications or were designated “12F Modified” with smaller vent connections or lower MAWPs. An example of a tank nameplate from one of the facilities is shown below.

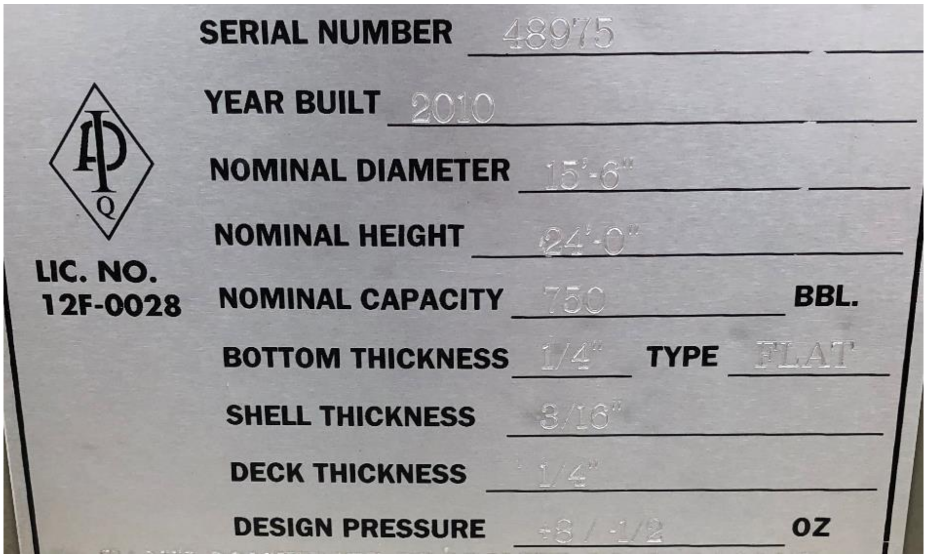
LIC. NO.
12F-0028
SERIAL NUMBER 48975
YEAR BUILT 2010
NOMINAL DIAMETER 15'-6"
NOMINAL HEIGHT 24'-0"
NOMINAL CAPACITY 750 BBL.
BOTTOM THICKNESS 1/4" TYPE FLAT
SHELL THICKNESS 3/16"
DECK THICKNESS 1/4"
DESIGN PRESSURE +8 / -1/2 OZ

Figure 3 - Nameplate of Existing API 12F Tank

This tank was designed to API 12F Specification from 2010 and had a design pressure of 8 oz/in^2 as well as a 3” vent connection. These two details required a much larger vent header to capture emissions due to the lower allowable backpressure and increased pressure drop across the vent connection. The table below illustrates the backpressure difference between a 3” vent connection and 4” vent connection at a larger 10 tank facility. The backpressure calculated for an identical 6” ventline was 14.5 oz/in^2 for a 3” tank vent nozzle compared to 10.1 oz/in^2 for a 4” tank vent nozzle. This means the vent system for a tank battery with 12 oz/in^2 thief hatch set points would not be adequately sized due to the nozzle size difference alone.

Table 4 - Comparison of Tank Vent Connection Size

Tank Vent Nozzle		3"	4"
Max Rate to Tanks	(bbl/d)	9,000	9,000
Flash Gas Rate	(Mscfd)	830.1	830.1
Displaced Gas Rate	(Mscfd)	101.1	101.1
Thermal Gas Rate	(Mscfd)	9.7	9.7
Design Rate	(Mscfd)	940.8	940.8
Vent Size		6"	6"
Tank Backpressure	(osig)	14.5	10.1

The table below illustrates the differences in vent capacity due to tank design pressure for a given vent system. This system was designed for a tank battery of 4 1,000 bbl tanks and consists of a 4” ventline routed approximately 200 ft away to a single flare tip. The maximum vent rate that can safely be handled by the system increases as tank design pressure increases. The target backpressure is based on 90% of thief hatch set pressure for a given tank. The equivalent maximum rate to tanks is based on a typical flash gas factor of 92.2 scf/bbl. It also accounts for required vent capacity due to thermal expansion and displacement.

Table 5 - Existing Vent System Capacity for Various Tank MAWPs

MAWP	oz/in2	2	4	8	12	16
Target Backpressure	oz/in2	1.8	3.6	7.2	10.8	14.4
Design Rate	(Mscfd)	101.2	145.56	208.75	257.5	298.8
Max Rate to Tanks	(bbl/d)	940.5	1369.3	1980.0	2451.2	2850.4

Replacing a tank with low design pressure or small vent connections is usually not cost efficient to save on vent line size. Whenever these issues were encountered in the field, other sources of pressure drop in the system were attempted to be minimized first. This sometimes required the selection of costlier, lower pressure drop flares or larger in-line flame arrestors in addition to larger ventlines. Another option that was considered were in-line blower systems to control the pressure in the tank vent space. Overall, lower pressure rated tanks and smaller vent connections led to costlier vent capture system designs. Installing new tanks on these existing sites was not an option, however, ensuring that tanks on new designs are built to adequate specifications for vent system design would avoid this issue in the future.

Another common issue for the existing sites was existing vent headers that were not adequately designed. Other equipment limitations existed for facilities that had tank vent systems installed with inadequate capacity. Flame arrestor, flare, and knockout selection are all crucial parts of the tank vent design. While repurposed equipment can save on costs, it must be the correct fit for the intended service. Vertical knockout vessels were installed on a number of facilities and were often inadequately sized for proper liquid droplet removal. Liquid carryover to the combustion device has the potential to cause smoking and inadequate combustion rates as well as pose a safety hazard to on-site personnel. Below is an image of a knockout that needed to be replaced on one of the facilities. The vent line was also pocketed on the outlet, rather than sloping back to the knockout. This is a collection point for liquids to build up and cause unexpected pressure drop or a freezing hazard in the ventline.

Figure 4: Vertical Knockout Vessel with Pocketed Discharge Line

In this case, a larger knockout vessel was required to meet the liquid separation requirements. Vertical knockout vessels typically do not achieve the same liquid droplet separation as similarly sized horizontal knockout vessels. The table below compares the maximum vapor capacity of a 24” O.D. by 4’-0” S/S knockout targeting a liquid droplet separation of 250 microns and larger on one of the facilities. The horizontal vessel can achieve the same separation at a higher vapor flowrate because the drag force on the droplet is not directly opposing the gravity settling force in a horizontal vessel. In a vertical vessel, the drag force acts the opposite direction of gravity settling and causes larger droplets to be swept into the outlet of the vessel and to the flare. This was a common issue with existing equipment and required larger knockout vessels when compared to horizontal vessels.

Table 6: Comparison of Vertical and Horizontal Knockout Capacity

Vessel Orientation		Vertical	Horizontal
Vessel Size		24" O.D. x 4'-0" S/S	24" O.D. x 4'-0" S/S
Operating Temp	(°F)	114	114
Operating Pressure	(psig)	0.5	0.5
MW (Vapor)		49.5	49.5
Z (Vapor)		0.888	0.888
Density (Liquid)	(lb/ft3)	47.64	47.64
Viscosity (Vapor)	(cP)	0.009	0.009
Minimum Droplet Size	(micron)	250	250
Maximum Flowrate	**(Mscfd)**	**1,219**	**1,458**

Flare selection is also an important step in design. Combustion efficiency is a requirement for compliance with Quad Oa and a number of flares were not meeting that requirement and needed to be replaced. The figure below shows one of the existing flares that needed to be replaced because it was not installed in the correct service. This flare was intended for high pressure systems where high velocity across the tip can ensure good mixing and combustion of the vent gas. Tank flares require flares designed for low pressure drop such as ball-tip flares or air-assist flares. Air-assist flares were installed on a number of the larger sites to help minimize the pressure required and handle the higher capacities.

Figure 5: Existing Flare That Was Replaced

Plot spacing and the location of new flares posed a challenge on a number of sites. Spacing requirements for flares are significantly higher than other types of equipment and room is limited on wellpad facilities. Spacing guidelines for flares can vary depending on operator, but it is typically at least 100ft from other equipment. Ground level radiation is also taken into account for flares, but the low flowrates off of tank vents is typically not a major concern at ground level. When possible, pad limits were extended to make space for the flare close to tanks. In some scenarios, the only available location was on the opposite end of the facility and made the design more challenging and costly due to increased piping length and size of the vent system. Additional flare tips were installed on the same flare stand when required to minimize the footprint of the flare. Sites with an existing high pressure flare we able to be retrofitted with a dual-tip or multi-tip flare without impacting existing equipment spacing.

Conclusion

Tank vent emissions can be broken into three categories: flash gas, displacement effects, and thermal effects. Understanding the impact of equipment design on the overall tank vent design rate can help to make more informed decisions. Acknowledging the effect of control valve operation, vessel operating conditions, and tank design criteria can help make informed decisions earlier in facility design and save cost on tank vent systems in the future. Evaluating existing equipment limitations and spacing requirements early on in the project can help prepare for the challenges that will be faced during design. Some of the challenges faced during these retrofits could have been avoided upfront with flexibility in design while others must be accommodated as they arise. We can apply the lessons learned from these retrofit facilities to make better informed decisions in the early stages of facility design as well as utilize some of the solutions on other retrofits in the future.

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