

“CAPTURING” THE TANK VAPOR OPPORTUNITY: REMOVING OXYGEN FROM THE PRODUCTION STREAM REDUCES EMISSIONS AND GENERATES INCREMENTAL ECONOMICS

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ABSTRACT

The term *Vapor Recovery* generally refers to the process of collecting the vapors (or flash gas) entrained in crude oil, well production wastewater, or other fuels stored in tanks, so they do not escape into the atmosphere. Several technologies have been used over the past 60+ years to make this process as efficient as possible. This paper showcases a multi-site comparison of several vapor recovery technologies and how they affect production performance as well as site emissions.

Most operators today utilize some combination of Vapor Recovery Units (VRUs) and Vapor Recovery Towers (VRTs) in order to capture as much flash gas on site as possible. These technologies have proved useful and economic depending on production rates and API gravities, however, they still leave some level of additional flash gas at the storage tanks due to a final pressure drop and longer retention time in the tanks. The challenge with this final volume of flash gas in the tanks is that it inherently becomes mixed with oxygen which can cause corrosion in pipelines and gathering systems. Due to this oxygen contamination, the flash gas from the tanks is typically flared or combusted on site.

This multi-site test was performed to assess the latest vapor recovery technology that allows for the capture and treatment of this additional flash gas volume and compare it to existing VRT technology. Separate tests were performed on different sites to provide a true head-to-head comparison as well as a comparison utilizing offset production data. This paper will show how using the latest vapor recovery technology can improve vapor recovery efficiency, greatly reduce on-site emissions, and create a safer on-site working environment.

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Introduction

The value of the vapors that are generated as a byproduct of the upstream processing of oil has long been under appreciated; however, this dynamic is shifting due to greater volumes produced at multi-well pads, increasing regulatory pressure, and the economic opportunity of capturing incremental profits through gas and NGL markets.

During the initial treatment of the raw well stream in 3-phase separators, gas is removed at wellhead pressure and introduced into a gathering line, while the liquid hydrocarbon (i.e. oil) stream often flows to a secondary separation process utilizing a low-pressure separator or vapor recovery tower (VRT). With a typical designed residence time of 30 minutes or less, and operation at less than 5 psig, flash gas / vapor is separated from the oil in the VRT and compressed by a vapor recovery unit (VRU) for introduction into the gas gathering line. The potential exists in most VRUs to introduce oxygen through its seals, valves, and piping, especially on the suction side. In a typical installation, experiential data indicates that a VRT will separate 75-80% of the potential flash gas / vapor stream. The oil stream then flows to large, atmospheric pressure oil storage tanks to improve oil clarity and prepare for transfer to downstream storage, via truck, or pipeline. Ironically, these atmospheric tanks perform the best separation of oil and gas on the well pad, driven by many hours of residence time, while the near atmospheric operating pressures (typically less than 10-12 oz / in² pressure, allowing low vapor pressure gases to be liberated) promote generation of a very rich, high BTU vapor stream. A typical pad arrangement is shown in Figure 1 below.

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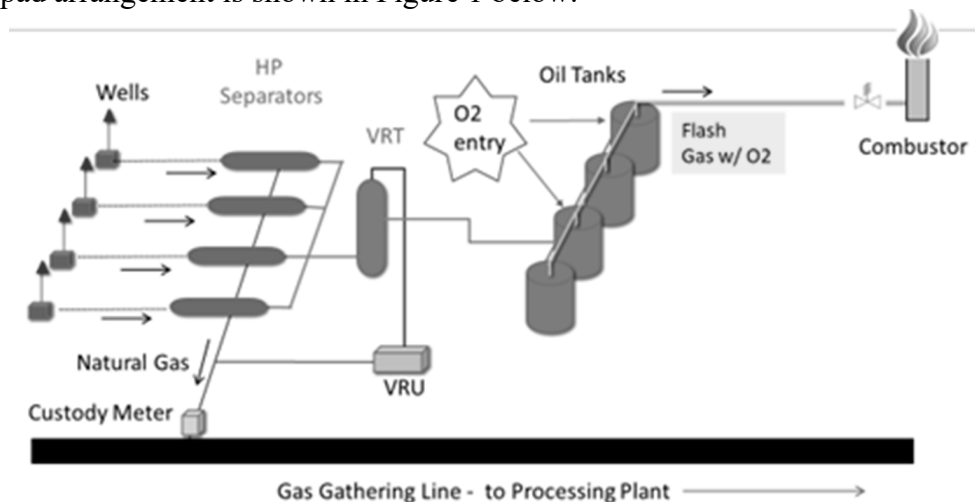


Figure 1: Site with Vapor Recovery Unit and Vapor Recovery Tower

Many operators, especially field personnel, have expressed frustration with the nagging operational issues associated with VRT's, including paraffin related freezing or clogging, and the inability to effectively process intermittent or unstable flow through the unit. These operational issues are typically experienced at multi-well production pads used to develop unconventional resources. The response to poor VRT reliability by some operators is to simply flow the oil stream directly from initial separation to the atmospheric storage tanks, bypassing the VRT completely. This practice, however, generates a much higher volume vapor stream to be managed, as illustrated in Figure 2.

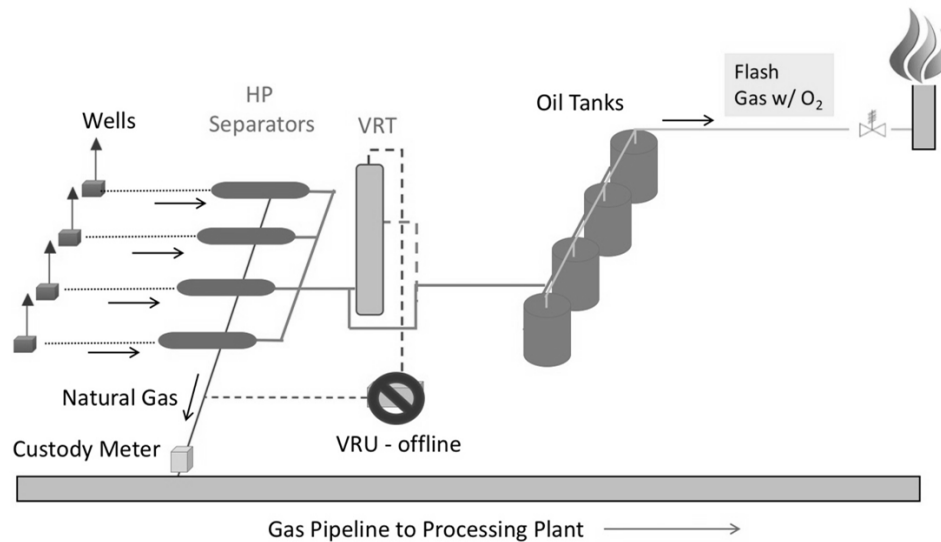


Figure 2: Site Without VRT or VRU to Accommodate Operational Concerns

The capture and sale of this higher volume, BTU-rich vapor stream presents the opportunity for the operator to simultaneously improve site revenue, de-risk the site from a regulatory perspective, and reduce site emissions.

It is a reasonable expectation to assume that regulations affecting air quality, especially those focused on restricting the emissions of NO_x and VOC, are unlikely to loosen and could potentially tighten in the future, resulting in higher gas capture mandates and less flaring. In addition, regulatory trends in some regions are beginning to effectively limit the number of wells co-located on a pad by capping total permitted emissions per pad; or increasing permitting complexity, cost, and time as emission levels increase. The emergence of ozone nonattainment areas, specifically in the Rockies, southwest Pennsylvania and South Texas, add complexity and time to the permitting process of a site with significant emission levels – currently defined as greater than 100 tons per year (TPY) of VOC and/or NO_x. Public reaction to flaring is becoming increasingly negative and vocal, as growing numbers view the practice as wasteful and damaging to the environment.

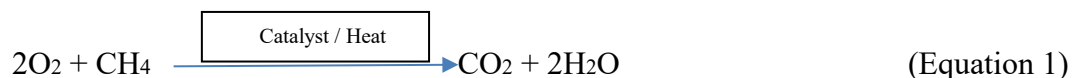
The ideal condition of a zero-emissions production pad can only be realized if all produced gas and tank vapors on a location can enter a gas gathering line and be sold – typically achieved through compression of flash vapor. Driven by ~3 psi of partial pressure of atmospheric oxygen and compounded by the near atmospheric operating pressures of surface storage tanks, oxygen readily becomes a component in the tank vapors by entering from the air surrounding the tanks and piping. If oxygen levels in tank vapor gas compressed into the gathering line exceeds pipeline specifications, pipeline operators typically have the contractual ability to shut in the flow from that location. Conventional methods of tank vapor management have many challenges that make them only marginally effective in many cases. Gas blanket systems are used to provide a barrier to oxygen entering an atmospheric storage tank. However, activities such as frequent opening of hatches to gauge or sample the tank, as well as the inability to precisely manage gas blankets at the very low tank operating pressures make gas blanket systems frustrating and ineffective for many operators. Gas blanket systems have the potential to send otherwise saleable product to atmosphere and increase emissions.

Pipeline operators, intent on protecting their assets from corrosion, have placed limits on O₂ content of all gas accepted into the line, many restricted to 10 ppm O₂ maximum or less. In addition, any O₂ content can affect efficient operation of mid-stream gas processing, such as amine systems.

Oxygen Removal Technology

A packaged solution¹ has emerged that can treat a compressed gas stream to reliably remove O₂ to concentrations well below pipeline limits. This equipment is capable of treating a gas stream comprised of up to 25% air (~50,000 ppm O₂) and reducing it to a typical outgoing concentration of less than 3 ppm. This allows for a vapor stream from atmospheric storage tanks to be compressed and reliably meet pipeline O₂ limits, allowing for a consistent revenue stream and eliminating process upsets associated with the gas stream being “shut in” and shifting to flare until the O₂ concentration returns to acceptable levels. With a consistent, reliable O₂ removal system on line, process upsets, unnecessary flaring, and/or urgent troubleshooting tasks to find and correct O₂ excursions in the process no longer occur. When applying for an emissions permit in many regions, the presence of the O₂ removal system will simplify and speed the permitting process while allowing for more wells to be co-located on a single site, improving economies of scale and capital efficiency.

The design and operation of the patented O₂ removal equipment has been refined over the last several years, and there have been over 200 installations of this equipment in all major US oil and gas producing basins. This technology utilizes a heated reactor contained within a pressure vessel reactor that utilizes a proprietary catalyst. The heated gas stream enters the reactor and the O₂ present is converted to CO₂ and H₂O per the reaction below (Equation 1).



¹ Patent Numbers: 8,992,838; 9,334,109; 9,764,255; 9,776,155

Resultant concentrations of both CO₂ and H₂O are less than the original concentration of O₂. Said differently, less CO₂ and less H₂O are generated than the amount of O₂ removed. Typically, longer-chain hydrocarbons react first – one pentane molecule can eliminate eight O₂ molecules.

This equipment is typically installed downstream of a VRU. If a screw compressor is utilized as the VRU, a scrubber is recommended because the catalyst can be coated by compressor lube oil which can coat or “mask” the catalyst, preventing its contact with O₂. Condensate and / or small amounts of entrained produced liquids don’t harm the catalyst. Liquids captured in the scrubber can be directed to the atmospheric storage tanks and serve as an additional revenue stream.

An on-skid recuperating heat exchanger serves dual purposes: pre-heating inlet gas to reduce power usage while simultaneously cooling discharge gas. The gas first moves through the heat exchanger to pre-heat incoming gas. The reaction is exothermic, and high O₂ concentrations can boost reactor temperatures to 600 F – contained within the code pressure vessel. The stream is then cooled to typical post – VRU temperatures of slightly less than 200 degrees Fahrenheit.

This equipment is intolerant to the presence of H₂S. Installations in sour gas environments typically rely on pre-treatment of the gas before it enters the unit. For additional protection, a reactant that will remove small amounts (less than 0.5 ppm) of H₂S can be added to the reactor.

While sensitive to H₂S, the oxygen catalyst is not consumed in the reaction and can be economically regenerated if poisoned by H₂S or coated with engineered lubrication oil.

Background of Operational Dynamics

The opportunity presented by the O₂ removal technology is to capture and sell the rich tank vapor stream that would otherwise be flared, while de-risking the site environmentally and improving the inherent safety of a production site by actively controlling / lowering tank operating pressures. The chart in Figure 3 below graphically captures the phenomena of vapor generation in the atmospheric tanks, where oil enters the tank and experiences a pressure drop that further liberates a high BTU vapor stream.

As shown, the quantity of additional vapor generated is typically 10-30 SCF / BBL, depending on API gravity.

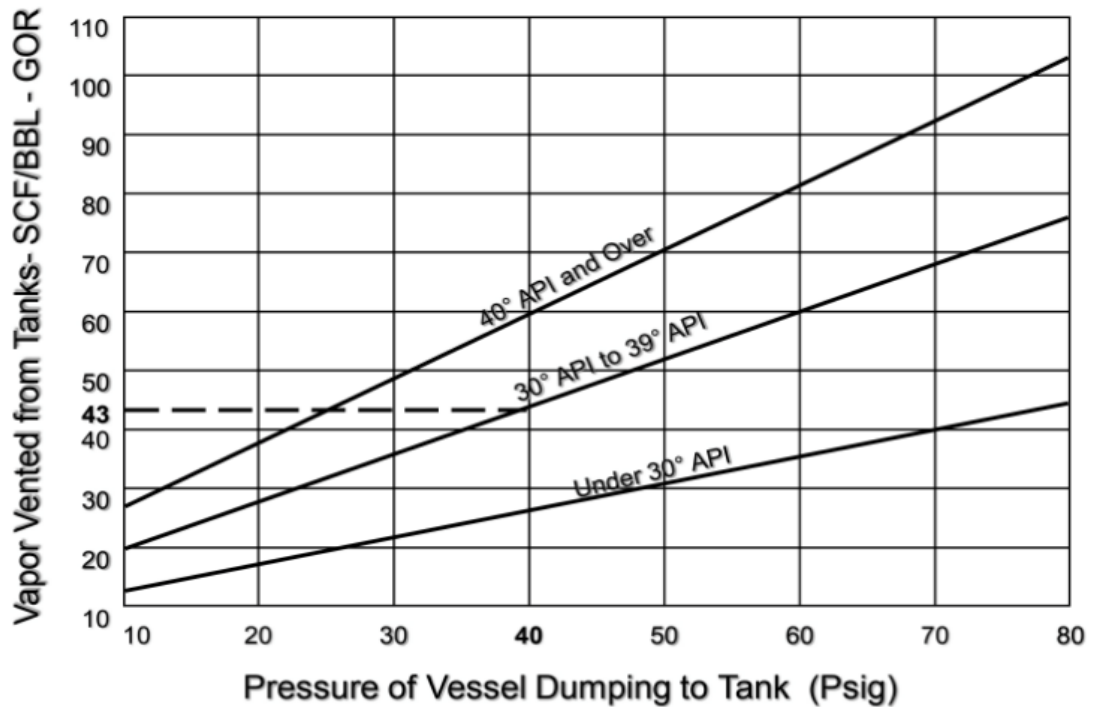


Figure 3: Estimated Volume of Tank Vapors²

² U.S. Environmental Protection Agency, *Installing Vapor Recovery Units on Storage Tanks*, October 2006.

Opportunity to Evaluate

Two major oil and gas production companies have partnered with the provider of O₂ removal technology to evaluate the equipment's reliability and effectiveness. The operators configured their process for a direct comparison between two sets of operating conditions on a single site for an accurate, head-to-head comparison.

The base operating case uses a VRT. Gas liberated within the VRT is compressed and sold, tank vapor is flared. The volume of VRU generated gas to the gathering line (MCF/day), tank vapor flared (MCF/day), as well as oil production (BBL/day) was measured in each trial.

The second set of trial conditions call for the VRT to be bypassed. All oil will flow directly from the primary separators to the atmospheric storage tanks, avoiding the VRT. The tank vapors were then routed to and compressed with the same VRU, which was re-tasked to compress tank vapors only; the gas then flows through the O₂ treatment equipment, is continuously sampled by an O₂ analyzer, and then any condensed liquids are scrubbed before gas is sent to the downstream gathering line. Scrubbed liquids were returned to the atmospheric oil tanks where the majority remained in liquid phase – repeatable results show a step function increase in oil sales in every trial.

A diagram showing base and trial test process configuration is illustrated in Figure 4. The process was originally configured for oil to flow through the VRT after initial separation, and was modified by both operators to accommodate the test case. Historically, vapor generated in the atmospheric storage tanks was flared, as allowed by the site's environmental permits.

Each trial is a direct comparison of two operating configurations – the first (a) with VRT online, with VRT gas stream compressed and tank vapor flared; the second (b) with VRT bypassed and tank vapor captured and compressed, treated to remove oxygen, scrubbed of liquids, and sold.

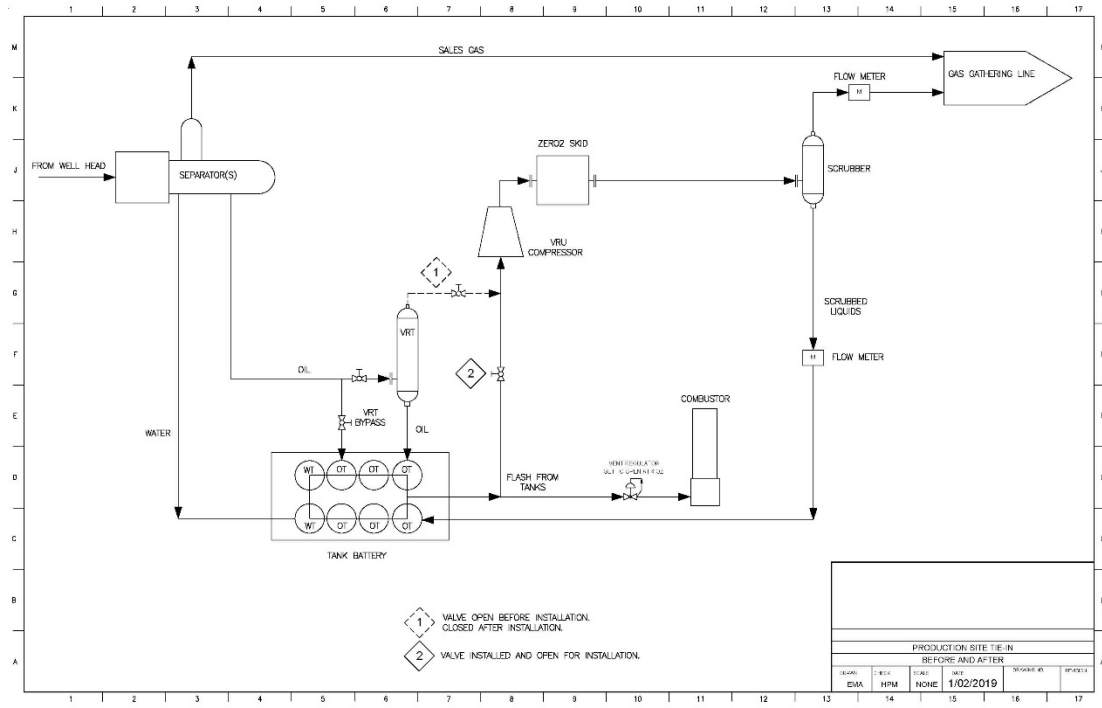


Figure 4: Trial Process Configuration

Each operator generously allocated operations resources and production time at both sites to evaluate the test scenarios.

The test plan and process configuration are defined below:

Test Protocol (1)

- VRT in operation. Vapors extracted from VRT are compressed and flow into gathering line
- Flaring of tank vapors

Test Plan: Operate facility for a period of at least 21 days with VRT online, and VRT based gas stream captured and sent to gas gathering line. Storage tank vapors are flared.

Variables measured:

- Gas sold (MCF/day)
- Oil Produced (BBL/ day)
- Vapors flared (MCF/day)

Test Protocol (2)

In each trial case, operate the facility with VRT offline for at least 21 days. Oil flows from initial separation to atmospheric storage tanks. Storage tank vapors are compressed through existing VRU, flow through oxygen removal equipment, and are then sent to the gas gathering line.

Test Plan: Operate site as described.

Variables measured:

- Oxygen removal equipment availability (hours available / hours of pad operation, expressed as a percent)
- Gas processed to gathering lines (MCF/day)
- Oil produced and sold (BBL/ day)
- Vapors flared (MCF/day)
- Days operated each set of process conditions

Installation

The installation of the oxygen removal equipment is very straightforward. The unit has one process inlet, one process outlet, a 4'x4' footprint and is skid mounted, containing an ASME Code vessel reactor, and a heater / heat exchanger arrangement that utilizes 480V, 3 phase power. The unit requires 40 kW for startup, and between 0-15 kW when operating at steady state. A programmable controller fully manages equipment operation. The heated gas stream flows through a proprietary catalyst bed, and the O₂ is converted to CO₂ and H₂O. The system measures outlet O₂ concentration (ppm) (also optionally measures inlet O₂ concentration), and this measurement is used as a control input. Every unit is equipped with a proprietary SCADA system that measures and reports several process variables in real time with 2-minute resolution. The system can also monitor other process variables from the VRU or elsewhere on the operator's pad.

Externally, the oxygen treatment unit requires 480V power to operate, and is flanged to connect to any VRU. A unit can typically be put on line within 1-2 days of deployment to a site.



Figure 5: Oxygen Removal Unit on a Production Site

Results

Operational Challenges and Observations

Depending on flow rate, operating pressure, and gas composition, a 3-15 psig pressure drop was observed through oxygen removal equipment, and is within the expected range for equipment and flow rate of gas through the unit.

The exit temperature of the gas out of the oxygen treatment equipment, post heat exchanger, was observed to be 190 degrees Fahrenheit, comparable to exit temperatures from a typical VRU.

The operating location experienced intermittent increases in gas gathering line pressure due to compressor booster station downtime which could not be matched by the VRU, causing VRU downtime. This condition was unrelated to the presence or operation of the oxygen removal system.

During one trial, process upsets, external to the oxygen removal equipment, caused fluctuation in gas gathering line operating pressures. This led to variation in VRU operation, which risked the introduction of VRU lube oil into the VRU outlet flow, and entering the oxygen removal unit. The equipment provider recommends utilizing a scrubber between VRU and oxygen removal equipment because, as previously stated, the oxygen removal equipment cannot tolerate significant or sustained flow of engineered lubrication oil. A scrubber placed downstream of the oxygen removal equipment, upstream of the gas custody transfer meter, also provides a means for capturing valuable NGL's to be sold as a sidestream or introduced into the atmospheric tank system, depending on processing capabilities downstream of the location.

Table 1 – Incremental Installation Costs on Site

	VRT INSTALLATION	BYPASS VRT / FLOW THROUGH OXYGEN REMOVAL EQUIPMENT CAPEX
CAPEX	\$28,000	\$5,000 (NO VRT required)
Monthly OPEX	-0-	\$3,600

The oxygen removal equipment can be purchased or leased. This analysis evaluates the opportunity based on the lease option economics.

Impact on Economics and Emissions

Economic evaluations and trial conclusions are summarized below, as well as sample calculations with stated assumptions of commodity pricing. It should be noted that the price an operator can secure for the sale of gas vapor is dependent on the pipeline and midstream contracts. Typically, tank vapor gas contains significantly higher BTU value, at times over 3000 BTU/MCF, which reflects a vapor stream rich with propane, butane, pentane, hexane, etc. If the midstream processor has the capability to effectively recover the longer chain components, the price per MCF can elevate far above standard Natural Gas commodity pricing. A transaction

price of \$4.50 / MCF is modeled below in a ~\$3.00 / MMBTU natural gas (NYMEX) commodity price environment, as a higher BTU stream was generated in these trials. Results will vary by application, depending on contract terms and pricing assumptions for each sales agreement.

The additional gas and oil volumes produced through the capture of tank vapors, made possible by the O₂ removal equipment, generated a substantial incremental revenue stream

Table 2 – Trial Results Summary

Trial	Days Operated	BOPD Increase		MCF/Day Increase		O ₂ Equipment Uptime
		BOPD	%	MCF/Day	%	
A	77	24.1	3.2%	51.0	37.2%	98.7%
B	128	4.3	13.5%	46.8	15.1%	99.2%
C	124	6.8	11.0%	46.0	14.6%	98.4%
D	67	15.7	18.9%	29.6	19.7%	99.2%

Table 3 – Economics of Oxygen Removal Equipment

Trial	Incremental Revenue (\$/Year)	NPV of Incremental Improvement Using O ₂ Equipment (1 Year, 10%)
A	\$544,250	\$429,545
B	\$156,485	\$109,079
C	\$74,200	\$41,074
D	\$255,605	\$190,996

Table 4 – VOC Emissions Profile Improvement (all amounts in tons of pollutant emitted per year)

Trial	Base Case VOC (Tons / year)	Trial Conditions VOC (Tons / year)	VOC Improvement
A	14.9	0.3	98.0%
B	13.6	0.3	97.8%
C	13.4	0.3	97.8%
D	8.6	0.2	97.7%

Table 5 – NO_x Emissions Profile Improvement (all amounts in tons of pollutant emitted per year)

Trial	Base Case NO _x (Tons / year)	Trial Conditions NO _x (Tons / year)	NO _x Improvement
A	1.8	0.1	94.4%
B	1.6	0.0	99.8%
C	1.6	0.0	99.7%
D	1.0	0.0	99.8%

Conclusions

In each trial, utilizing the oxygen removal equipment and removing the vapor recovery tower from service produced significant benefits, including (a) improved profitability and return on investment, (b) substantial reductions in emissions of VOC, (c) reduction / elimination of flaring, and generation of NO_x, and (d) de-risked the production sites both environmentally and through flow assurance.

Operational benefits include inherently safer production sites by reduced / controlled tank pressures, a streamlined permitting process, and the opportunity to co-locate additional wells on a future pad without concern about permitting limits, thus conserving capital expenditures associated with additional site development and related lease operating expenses.

APPENDIX

Trial Data: Details of Revenue and NPV Calculations

Gas (\$/MCF): \$4.50

Oil (\$/BBL): \$55.00

Days/year: 350

<i>VRT Base Case - Configuration A</i>								
Trial	BOPD	MCFD	Revenue	Equipment Lease (\$/Year)	Net \$/Year	CAPEX	NPV 10% 1 Year	NPV 10% 2 Years
A	1003.5	137.0	\$ 19,533,150	\$ 55,200	\$ 19,477,950	\$ (25,000)	\$ 16,074,752.07	\$ 30,708,824.19
B	31.8	309.5	\$ 1,099,613	\$ 55,200	\$ 1,044,413	\$ (25,000)	\$ 840,423.55	\$ 1,625,106.12
C	61.5	350.0	\$ 1,735,125	\$ 55,200	\$ 1,679,925	\$ (25,000)	\$ 1,365,640.50	\$ 2,627,793.01
D	83.0	180.2	\$ 1,881,565	\$ 55,200	\$ 1,826,365	\$ (25,000)	\$ 1,486,665.29	\$ 2,858,840.35

Note: Equipment Lease is VRU

<i>Tank Vapor Capture - Configuration B</i>								
Trial	BOPD	MCFD	Revenue	Equipment Lease (\$/Year)	Net \$/Year	CAPEX	NPV 10% 1 Year	NPV 10% 2 Years
A	1027.6	188.0	\$ 20,077,400	\$ 98,400	\$ 19,979,000	\$ (8,000)	\$ 16,504,297.52	\$ 31,514,815.93
B	36.1	356.3	\$ 1,256,098	\$ 98,400	\$ 1,157,698	\$ (8,000)	\$ 949,502.07	\$ 1,819,297.33
C	68.3	314.0	\$ 1,809,325	\$ 98,400	\$ 1,710,925	\$ (8,000)	\$ 1,406,714.88	\$ 2,692,158.15
D	98.7	150.6	\$ 2,137,170	\$ 98,400	\$ 2,038,770	\$ (8,000)	\$ 1,677,661.16	\$ 3,209,419.23

Note: Equipment Lease is VRU plus ZerO₂

<i>Summary Difference</i>								
Trial	Increase BOPD	Increase MCFD	Incremental Revenue	Equipment Lease (\$/Year)	Net \$/Year	Diff in CAPEX	Increase in NPV 1 Yr	Increase in NPV 2 Yrs
A	24.1	51.0	\$ 544,250	\$ 43,200	\$ 501,050	\$ 17,000	\$ 429,545	\$ 805,992
B	4.3	46.8	\$ 156,485	\$ 43,200	\$ 113,285	\$ 17,000	\$ 109,079	\$ 194,191
C	6.8	46.0	\$ 74,200	\$ 43,200	\$ 31,000	\$ 17,000	\$ 41,074	\$ 64,365
D	15.7	29.6	\$ 255,605	\$ 43,200	\$ 212,405	\$ 17,000	\$ 190,996	\$ 350,579