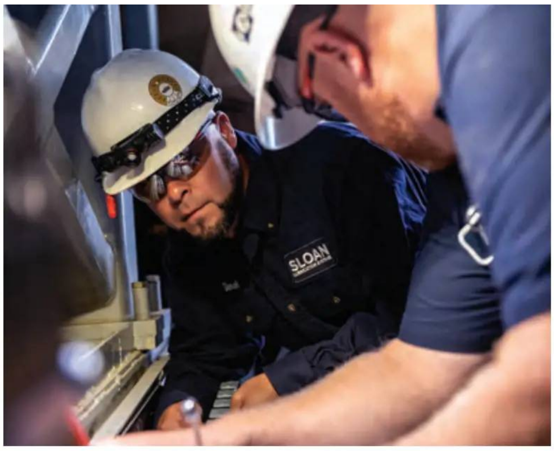

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EDITOR'S NOTE: This technical paper was to be presented at the 2024 Gas Machinery Conference, which was cancelled because of Hurricane Milton. The paper will instead be presented virtually via the SGA and will be presented in person at the rescheduled GMC in Q1 of 2025.

Lubricant reduction

Data analysis of gas quality improvements and operational/maintenance results from 3-1/2 years of a successful 90% reduction in compressor cylinder lubrication rates.

By **Seth Johnson** and **Matt McCarthy**

Introduction

Early in 2020, a meeting was held in TCE's Charleston office to address one of the top operational concerns at the time. It was identified that liquids in the gas stream were increasing, causing gas quality issues. This increase could be attributed partly to new shale gas sources, but also to the oil used to lubricate the cylinders of the reciprocating gas compressors throughout the system. The meeting was set to discuss methods to remove excess oil from the gas stream.

The thought was to install 14 filters/coalescers at strategic locations throughout the system costing nearly $1,000,000 per installation. (**Note**: only 6 or 7 filters were installed in the project.) Attending that meeting were key people from Pipeline Integrity, Reliability, and others. One gentleman attending from the Reliability group said, "Wait a minute, let's just not put the oil in there in the first place." He had learned of a solution whereby OEM recommended oil rates to gas compressor cylinders could be reduced by up to 90%. He knew several locations in the TCE footprint had changed to non-lube cylinders, but that methodology often led to increased maintenance costs, increased operational costs, and shortened maintenance intervals.

This brainstorming session led to a capital program comprised of 3 key aspects:

- Optimization of compressor lubrication.
- Installation of filter/separators on gas gathering compressor station inlets.
- Installation of mainline gas analyzers at several points of the pipeline system to better track gas quality as it moves through the system.

As the program developed, TCE chose to install an optimized oiling system solution on 134 compressors that were identified as having the biggest impact. These units included 120 legacy slow-speed units and 14 newer high-speed compressors. The units were all in the Columbia Gas system and were spread across 6 states including Pennsylvania, Ohio, West Virginia, Virginia, Kentucky, and New York. By the end of the 2nd quarter, commissioning of the new units was underway; 133 of the 134 units were operational by the end of 2020.

This paper is the 3rd in a series on this optimized method to reduce oil use in a reciprocating compressor cylinder. This research focuses on the comparative results after 3-1/2 years of operation by reviewing oil usage, maintenance issues of the new equipment versus the legacy systems, maintenance issues of the new lubrication strategy versus the legacy method, and any changes to oil volumes captured during pigging operations. The research methodology also employed interviews of maintenance leaders and end users to get a sense of the overall effect of this reduced contamination of the gas stream.

Overview of the program

The lubrication equipment upgrade program was completed in 2020 and faced many challenges related to the COVID-19 pandemic.

The upgraded compressors are primarily in transmission service, with several locations serving "double duty" in gas gathering, storage injection, and both storage withdrawal and transmission depending on the season and system demands.

The surveyed units represented a wide variety of types, sizes, and conditions. The oldest units are 1952 GMW6-2 machines running at 250 RPM, while the newest was a 2018 JGK/4 at a speed of 1200 RPM. Drivers consisted of 2 stroke lean-burn integrals,

methodology

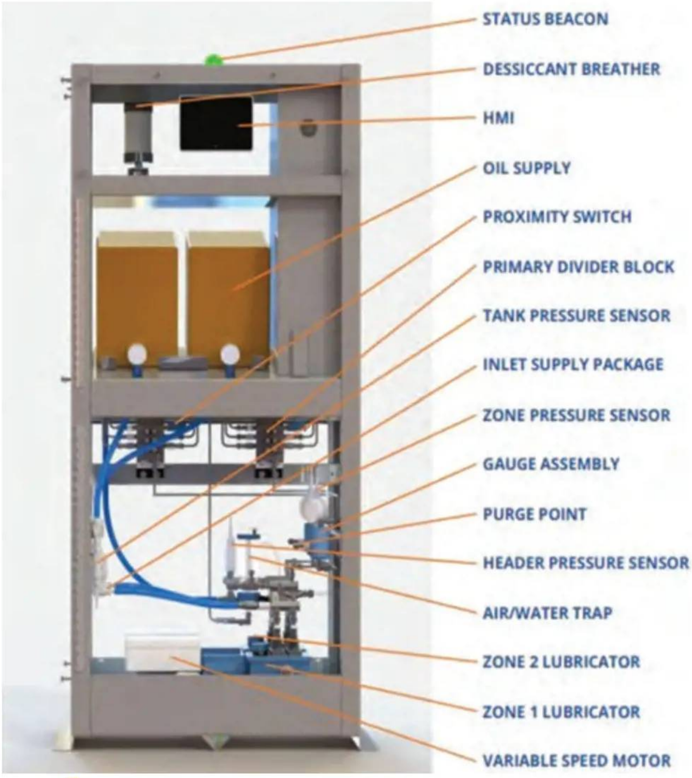


FIGURE 1 TriCip lubrication system components.

4 stroke rich-burn integrals, electric motor separables, and separable gas engines. Some units already had modern or well-maintained lubrication systems in place, sometimes factory new, while some had 40+ year old systems in poor condition. (C.J. Sloan, 2021)

Note: For an in-depth review of the project, refer to, GMC 2021, TP47 Gas Quality Improvements Targeted Via 88% Reduction in Compressor Cylinder Lubrication Rates.

Understanding the problem

Defining the challenge that TCE faced required a detailed look at several unique conditions:

OIL USAGE

- To lubricate the reciprocating compressors TCE injected oil into the compressor cylinders which later. migrated into the gas stream.
- Oil is more expensive every year, and operational costs continue to climb.

PIPELINE CONTAMINATION

- All the oil injected into the compressor cylinders finds its way into the pipeline. Once there, oil will collect at low points in the pipe.
- These liquids restrict flow, can cause material integrity issues, and can damage downstream equipment.
- TCE has an extensive, expensive pigging program to remove these liquids from the pipeline.

METER STATION CONTAMINATION

- Some of the oil that enters the pipeline can find its way to measurement stations at customer receipts.
- These fluids can affect the accuracy and reliability of the measurement equipment.

FIGURE 2 TCE lube oil data screen.

STORAGE FACILITY IMPACTS

- Some of the oil that enters the pipeline can find its way to storage facilities where TCE keeps gas on the ready to respond to customer's needs.
- Once the pipeline liquids go into a storage wellhead, they reduce the cavity volume available for gas storage and are extremely expensive to remove.

OEM LUBE RATES CAN LEAD TO OTHER MAINTENANCE/ ENVIRONMENTAL ISSUES AS WELL. FOR INSTANCE:

- Compressor valve failures.
- Compressor piston ring seizure.
- Automation and control equipment malfunctions or failures.
- Pressure pulsation control devices can become ineffective.
- Gas coolers can become ineffective.
- The shortened lifespan or catastrophic failure of gas filtration media.
- Unintended expulsion of liquids during gas venting.
- Unintended actuation of pressure control device.
- Increased GHG emissions due to maintenance events.

THE SOLUTION DESIGN: Optimization of the delivery method

To optimize oil injection rates, the oil delivery system, (fig. 1), must be properly designed for the application and be exceptionally reliable. It must include a means for accurately measuring oil injection volumes and triggering a failure alarm to prevent equipment damage. A compressor operator should never assume that an existing force-feed oil system is working properly when undertaking a lube rate reduction project. There are failure modes in these devices that may evade automated detection methods used on legacy systems.

For this program, TCE selected a newly developed oil delivery system. This design combines a proprietary lubricant with a redesigned lubrication system that utilizes advanced programming and components capable of both monitoring and control. Accuracy and reliability are critical because a 90% reduction in lubricant reduces the margin of error. Standard OEM lubrication rates are sufficient to cover up some lubrication system deficiencies or supply contamination, but in this case, precision is a must.

The design employs a freestanding enclosure containing two 20-liter containers of compressor oil blended to work specifically with Teflon materials, a pumping mechanism, and a divider block. The pumping mechanism features a computer-controlled direct current (DC) variable-speed gear motor driving two lubrication pumps. Oil flow to all delivery points is monitored through a divider block located within the cabinet. An electrical contact switch on the divider block assembly provides the onboard Programmable Logic Controller (PLC) with divider block cycle rate timing. This is used to calculate the current flow rate. The PLC continually adjusts the motor's speed to maintain the desired flow rate as a function of compressor speed.

Oil supply reservoir levels and pressure stability are monitored via multiple pressure sensors providing data to the PLC. This control logic automatically switches between a depleted container and the reserve container or can trigger an alarm if a leak is detected. Each container lasts 2-6 weeks depending on the size and speed of the compressor being lubricated. A touchscreen human-machine interface (HMI), (fig. 2), incorporated into the control system provides operators with up-to-the-moment system data. System setup and operating parameters are also accessed through the HMI display.

The redesigned lubricant

This oil reduction method requires a lubricant designed specifically for gas compressor cylinders which have Teflon-based materials. With an ISO 68 weight, this lightweight, mineral-based fluid flows even

FIGURE 3 Oil container modules.

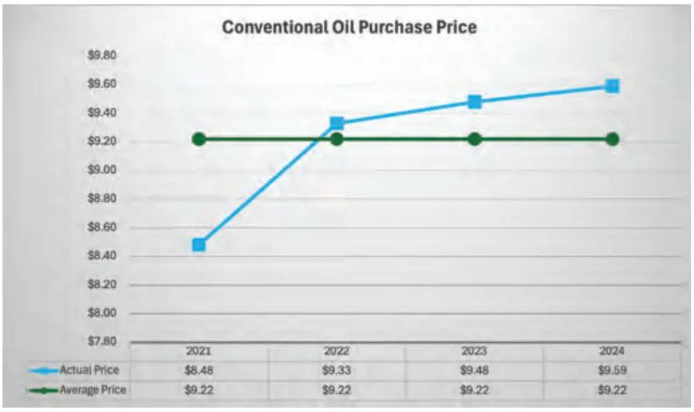
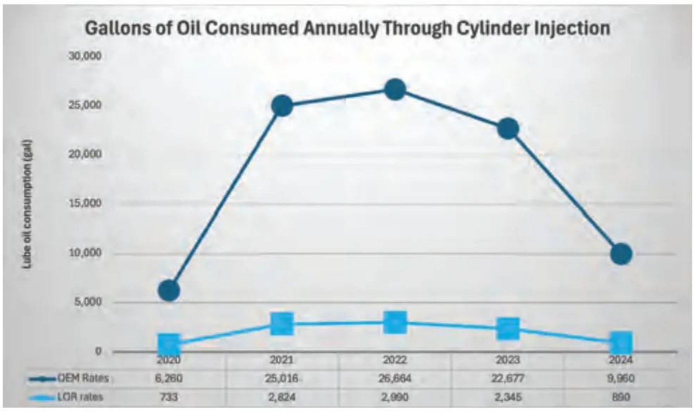


FIGURE 4 (Above).

FIGURE 5 (Below).



in cold temperatures, pour point is -25F. It adheres effectively to common wear surfaces and materials like Teflon. The lubricant formulation provides the physical properties enabling the oil to remain in place even when the fluid is acted upon by pressure differentials, mechanical sheering forces, gas flows, and the negative impacts of contaminants found in the gas stream. Additionally, the lubricant is non-reactive, contributing to its stability and reliability. It is packaged in prefilled 20-liter portable containers, (fig. 3), that safeguard it from environmental contamination, ensuring it remains clean and dry until needed.

This lubricant has been uniquely designed for compressor cylinders and should not be used in crankcases or engines. Although it is compatible with lubricating fluids found in this equipment, it lacks essential additives needed to prevent metal-to-metal wear in common equipment applications like journal bearings. While incidental amounts will not be detrimental, it is not suitable for engine use.

Optimization of the injection quantities

The flow rate methodology development began by dividing the units into two major groups: slow-speeds (less than or equal to 600 RPM) and high-speeds (greater than 600 RPM).

For slow-speed units:

- The compressor cylinders and packing were combined into a single delivery zone.
- The design rate for cylinders is 20MM Ft2 / pint of fluid (million square feet per pint), with the packing receiving half of the cylinder's rate.

For high-speed units:

- Precautions were taken to prevent heat buildup in non-cooled packing cases, which led to the cylinders and rod packing cases deliveries being split into separate zones.
- This provides the ability to adjust each independently of the other and/or to deliver separate fluids to each.
- The design called for all high-speed units to receive 7.5MM Ft2 / pint to the cylinders and OEM recommended delivery rates and oil to the packing cases.

THE RESEARCH FINDINGS: Injection rate adjustments

Maintenance inspections conducted since 2021 have led TCE to make a change to the packing oil and delivery rates on most high-speed units. This change was made to maximize packing lifespan and performance. TCE chose to convert these deliveries back to crankcase oil.

Operational challenges

As with most manufactured equipment and electronics, there's a certain level of infant mortality that can be expected with new components. Research revealed that this program did not completely avoid this, but all issues were minor.

On average, each unit has 59 "fail-able" parts, totaling 7,906 across the entire project. The only issues were related to infant mortality issues on the proximity switch used to monitor the divider block function, a few logic control boards, and several DC motor factory wiring problems. From the reviewed maintenance records, very few parts failed. With on-hand spares available for quick repair, no significant downtime has been experienced.

Oil consumption comparison

TCE purchases oil by the tanker load for compressor stations. Even with those volumes, oil consumption and pricing can be challenging for the budgeting process. The research included a review of purchases for October 2021 through July 2024 for the TCE Columbia Gas pipeline. Those records show that the average 40-weight oil purchase price ranges from $8.01/gallon to $10.49/gallon. The average purchase price is $ 9.22/gallon, (fig. 4), over the data period. The new proprietary lubricant was purchased for $46.00/gallon over the same period.

When comparing the optimized lubrication methodology versus the OEM suggested rates previously, the research revealed that TCE decreased oil injection rates from 90,577 gallons of conventional 40-weight oil to 9,782 gallons of the optimized lubricant. The following graph (fig. 5) shows what oil consumption would have been vs. the reduced flow rates. Note that for this data comparison, 25% of the total 2020 run hours were used as a conservative estimate accounting for the lube oil reduction phased in across the system starting in June and completed in December. The 2024 data was the partial year through June 2024, (fig. 5). The monetary impact of those savings equates to net oil cost savings of $385,000 over the 3 -year period.

The research revealed that TCE prevented 80,795 gallons of oil from being injected into the pipeline. The environmental benefit of this number alone is impressive. Not purchasing 80,795 gallons of oil means it was not produced, or transported, leading to a measurable reduction in carbon footprint. It was also not pumped into the gas stream where it would have caused liquids contamination in filters, drips, knockouts, and metering stations, leading to obstructions, reduced efficiency, equipment damage, and downtime. The cost of these negative impacts exceeds the expense of the oil and the savings from reducing them are significantly higher than the savings due to reducing purchased oil alone.

Maintenance records revelations

Maintenance records from 2017 through 2023 were reviewed. These were broken into three categories: unplanned shutdowns, maintenance work orders, and corrective work orders. Analysis revealed a significant decline in maintenance activity related to compressor cylinder valves. Overall, post lube oil reduction (LOR), there was a notable drop in both the number of valve-related incident records and actual recorded labor time devoted to valve repair and maintenance.

There was a total of 173 records of valve-related records spanning six and a half years between April 2017 through August 2023. 120 of those records were entered prior to LOR, 69.4% of the total. 53 records were after LOR implementation, 30.6% of the total.

Work hours recorded on each record over this time total 2620 hours. Before LOR, there were a total of 1,842 hours, 70.3% of the total. After LOR there were 778 hours, 30% of the total. Both the total number of records and total work hours recorded demonstrate a consistent reduction, (fig. 6).

In 2016 TransCanada acquired CPG and a new work management system was introduced. Throughout 2017, one station at a time began entering data, therefore some stations' data was not included for the entire time that year. Beginning with 2018, data shows the number of compressor valve events and hours worked for all 134 units discussed in this paper. The chart shows that after the oil reduction program was commissioned in 2020, the number of compressor valve events and hours worked drastically reduced each year. Had the records starting in April of 2017 included all stations, the reduction percentages would have likely shown an even larger reduction of required maintenance.

In summary, this drop in compressor valve maintenance is a direct result of reducing excess oil passing through the compressor valves.

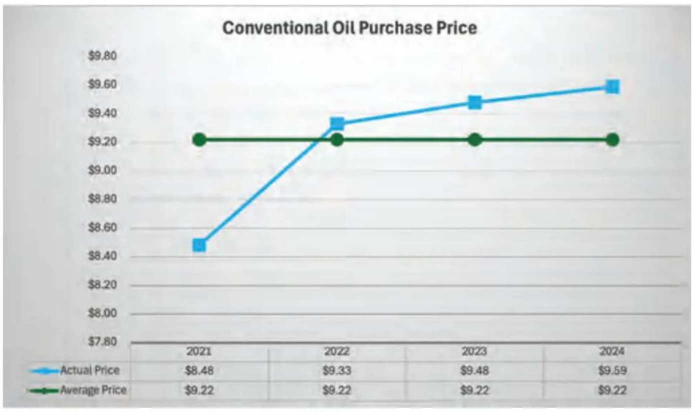


FIGURE 6

FIGURE 7 **Pipeline.**

Trends of pipeline liquids removed during pigging operations

The data led the researchers to evaluate the historical trends of pipeline liquids. TCE uses pipeline pigs, (fig. 7), to remove liquids and solids that are present. One of the most common pig designs is a squeegee pig which is highly effective at pushing liquids to a removal point. The data does not focus on individual pipelines as there are often multiple pipelines in the right of way (ROW). The data solely focuses on how much oil was removed through pig runs on that segment or ROW each year. The data in the graphs below show the historical trends of 2 key

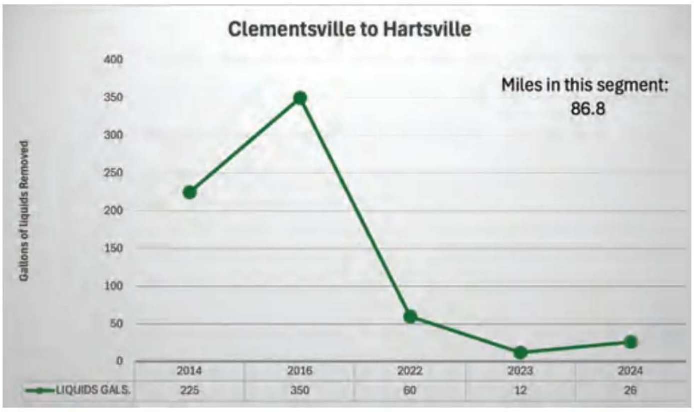
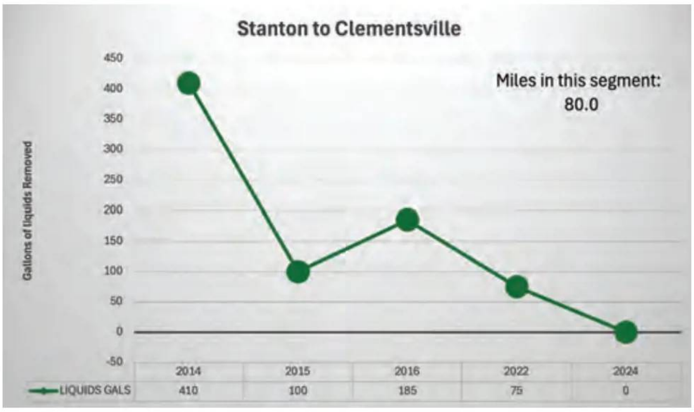


FIGURE 8 (Above). **FIGURE 9 (Below).**



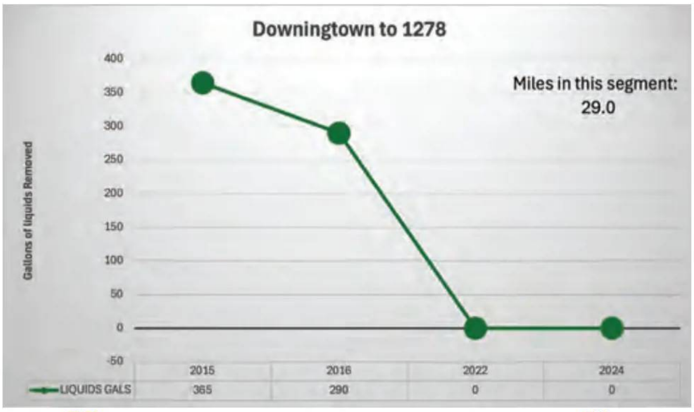
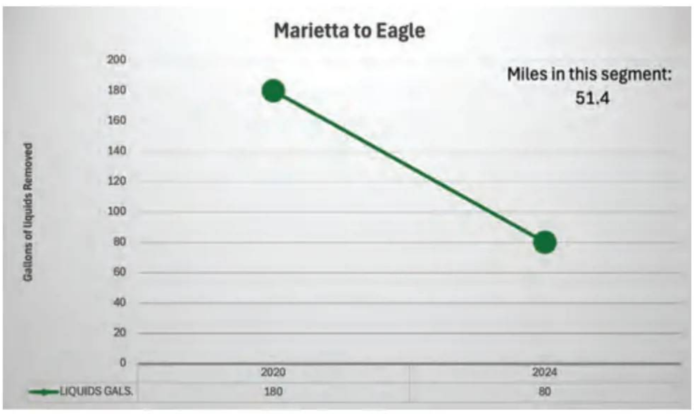


FIGURE 10 (Above). **FIGURE 11 (Below).**



areas selected by the research team.

The first area is centered around the Clementsville Kentucky compressor station, (figs. 8 & 9). The researchers chose this point as it is a gateway section from Columbia Gas to the Columbia Gulf system. All the gas being shipped through the Columbia Gas assets from the Marcellus and Utica shale reserves to the Gulf Coast liquified natural gas (LNG) plants pass through this area.

The second area was in eastern Pennsylvania, (figs. 10 & 11). The researchers chose this area because it is a key delivery point on the other side of the Columbia Gas system that has a history of captured liquids. Gas in this area is delivered in and around the metro Philadelphia area. Again, the main source of production is the Marcellus and Utica shale reserves.

Each data set from both areas clearly shows significantly reduced volumes of pipeline liquids following the 2020 lubrication optimization program.

Downstream improvements found

Kenova Case Study: TC Energy's Columbia Gas Kenova Compressor Station collects well-sourced raw natural gas and sends it to a neighboring company for extraction to remove contaminants and heavy hydrocarbons, producing a cleaner pipeline-quality natural gas which is then returned to the Kenova station where it is recompressed to pipeline pressure.

The Kenova facility features nine compressor units: four GMWA-8's (units 1-4) and

FIGURE 12
Processing plant inlet filter.

four KVG-410's (units 5-8), all installed in 1959, and one, (unit 9), installed in 2001. Units 1-4 and 9 receive the incoming gas after it passes through an initial filter/separator. They compress the gas and pass it through an outbound filter/separator before sending it to the processing company located adjacent to the Columbia station.

The gas is filtered upon entering the complex. Oil that collects in the filter vessels is drained into a waste tank and removed at a significant disposal cost. The gas is then re-compressed and filtered again to remove any remaining oil and water before undergoing the dehydration process. This now dry, clean gas is cryogenically processed to separate the heavier

FIGURE 13
Processing plant inlet filters.

hydrocarbons. The primarily methane gas is then returned to the Kenova Station, where units 5-8 compress it to pipeline pressures before introducing it into the gas transmission pipeline.

In 2001, the addition of unit 9, at Columbia increased oil requirements by 68 pints per day (PPD), leading to an overload of oil contamination in the processing facility's inlet filter system. To address this, Columbia installed a discharge filter and drip pot between the two facilities. However, these measures were insufficient, and the processing facility continued to experience problems with a saturated inbound gas line filter. This resulted in frequent maintenance issues such as waste oil drainage and costly maintenance. Unfortunately, records detailing the frequency and costs of these issues were not kept, leaving only recollection of the problems caused.

Since the installation and commissioning of the system in June 2020, these issues have been resolved according to a company representative. He noted, "Inbound filter maintenance is now reduced to routine preventive maintenance.

Although exact cost savings are difficult to quantify, the improvements have been significant. At the old flow rates, oil usage at the Columbia facility for units 1-4 and 9 would have been 11,920 gallons over the 4 years since the new systems were commissioned. Actual oil consumption post lube oil reduction was only 981 gallons. Total oil consumption has decreased by 10,939 gallons over that time.

Completing the picture, the gas is returned to the Columbia station. Units 5-8 compress it before being discharged into the pipeline as transmission-quality gas. Looking at the consumption of units 5-8, oil reduction has decreased by 3,368 gallons.

There is an overall station oil reduction of 14,307 gallons. With an average cost of $9.22 per gallon for traditional oil, this reduction alone has saved approximately $77,171 in oil costs, (table 1).

Oil cost is a small fraction of the total savings compared to the high cost of filter maintenance, the disposal cost of the collected oil, and lost production due to downtime; the overall savings can be conservatively estimated in the hundreds of thousands of dollars in this one example alone.

Conclusion

There are significant, quantifiable benefits to the lubricant reduction methodology TCE employed during the LOR program.

KENOVA OIL CALCULATIONS SUMMARY		
15,795.6	Gallons oil	Total oil consumption if no LOR*
$9.22	Avg cost per gallon	
$145,635	Oil cost if no LOR*	
1,488.3	Gallons oil	Total oil consumption with LOR
$46.00	Avg cost per gallon	
$68,464	Oil cost with LOR*	*Lube Oil Reduction
	$77,171	Actual oil cost savings

TABLE 1

The research revealed that TCE decreased oil injection rates from 90,577 gallons of conventional 40-weight motor oil to 9,782 gallons of the optimized lubricant, an 89.2 % reduction in oil consumption. Maintenance records show an approximate 40% reduction in both the number of valve-related maintenance events and man-hours spent repairing valves post LOR, indicating that reducing compressor cylinder lubricant increased the reliability and lifespan of these critical components. Pipeline pigging records of four pipeline segments totaling 247.2 miles of pipe show a drastic reduction of collected fluids. The segments analyzed represent just 2.2% of the total TCE Columbia system; however, this data is a good representation of the benefits across the entire pipeline.

In addition to the easily quantified data presented in this paper, it is important to keep in mind that there are benefits that are not easily quantified. Some of these include the cost of collecting and disposing of excessive amounts of lubricant from pipelines and compressor station piping, the cost of components needed to repair or replace compressor valves, the cost of replacing or servicing saturated filters, expenses related to reduced throughput from pipeline restrictions, the cost to clean or repair fouled metering stations, or expense from downtime in any of the key areas impacted by excessive lubrication. In addition to these difficult to quantify areas, other potential benefits need to be considered to complete the picture. One is the reduced exposure to the risk of damaging critical downstream equipment like gas turbines: A set of fuel gas nozzles, which can be damaged by excessive lubricant can cost as much as 1.5 million dollars. Another important consideration is the cost of alternate means of solving the problem. TCE's initial proposal was to install up to 14 inline filter/coalescers at a cost of nearly 1 million dollars each. While these may have solved some of the problems, they still would have been using the same amount of lubricant. A final necessary consideration is a fact that the amount of lubricant consumed has a direct quantifiable impact on greenhouse gas emissions, and excessive lubricant also increases the likelihood of maintenance events that require station blowdown. Reducing the amount of lubricant required for compressor operations does not just improve the bottom line, it also helps pipeline operators meet their environmental commitments. CT2