The High Cost of Over-Lubrication: Quantifying the Negative Impacts of Excessive Power and Compressor Cylinder Lubrication on Natural Gas Pipeline Operations

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Introduction

The purpose of this paper is to identify the impacts of excessive compressor and engine lubrication on specific aspects of pipeline operations and to create a useful model to help pipeline operators understand lubrication costs and the impact excess lubricant may have across an enterprise.

A common misconception about the purpose of lubricant optimization in reciprocating gas engines and compressors is that the primary targeted benefit is cost reduction via the decrease in consumed lubricant. An industry engineer we interviewed for this paper shared this anecdote - that when seeking approval to perform a compressor cylinder lubrication survey and subsequent optimization on 51 reciprocating compressors at 16 compressor stations, he claims he “made a rookie mistake,” when he pitched the project to his supervisor on the grounds of saving money on lube oil. When his supervisor looked at the dollar amount he could save, he said, “Well I don’t care about that… What keeps me up at night is keeping the customer happy.”

What the supervisor was alluding to is one of the many downstream impacts of over-lubrication. Any lubricant that goes into the pipe is going to end up somewhere. And depending on the location, it may end up causing one or more of a host of issues. These issues directly impact compressor operators and their customers by fouling equipment, adding to disposal costs, decreasing system reliability, and contributing to gas stream contamination.

Over-lubrication is an underappreciated problem for natural gas pipeline operations. The effects of over-lubrication can be experienced far from the equipment being lubricated and are often hidden by the method of reporting on and remediating the effects. For example, an over-lubricated compressor causes lube oil carryover which can foul filters, contaminate metering stations, contribute to pipeline varnish, reduce pipeline flow, create valve stiction, damage critical downstream equipment like turbines, and increase the cost and frequency of pigging operations.

Pigging operations are an excellent example of how some of the impacts can be hidden. Most pigging operations are scheduled events for the purposes of pipeline integrity; however, excess lubricant leads to more cleaning runs, and increased waste disposal. There is a very real cost to that in terms of money, man hours, and additional resources for the operation, but determining how much of that expense could have been avoided by addressing compressor over-lubrication is a real challenge. Typically pipeline operators absorb these additional expenses as the cost of doing business unless there is a major issue like metering station contamination, which forces them to take a closer look. Often these costs are also part of the pipeline operations rather than compression operations even though the source of much of the fluid collected is from compression.

In this paper, we focus on the larger picture of pipeline wide impacts and costs of excess lubrication to engines and compressors.

Model pipeline

In order to attempt to address and quantify these concerns, the paper authors have chosen to build a model pipeline as a mathematical analogue based on real world pipeline performance data. This model pipeline then permits estimation of costs resulting from higher than required compressor lubrication rates.

For inputs, we analyzed four segments of transmission pipeline. Three of these segments consisted entirely of horsepower generated from legacy Slow Speed Reciprocating (SSR) engine / compressors, and one segment consists of nearly entirely High Speed Reciprocating (HSR) compressors with separate natural gas engine or electric motor drivers. Each segment is approximately the same length and contains the same number of compressor stations (3). One of the SSR pipeline segments has implemented a reduced compressor lubrication program in the form of TriCip [1]. From that input data, we were able to arrive at a scalable baseline lubrication rate for each pipeline segment, in terms of Pint / Mile / MMSCFD. For the SSR compressors, the integral engines are also force-feed lubricated so a Pint / Mile / MMSCFD value was also determined for the engine side. Of those engines, ¾ were directly lubricated 2 Stoke Lean Burn (2SLB) and ¼ were 4 stroke with valve guide injection only.

Using these inputs, we were able to build a representative model pipeline using the averaged lubricant delivery rates for all the units in our sample segments, normalized for distance and segment gas flow.

Lubricant consumption

Our model pipeline consists of a 1000 mile (1609 km) gas transmission line with an average throughput of 1,000 MMSCFD (1 BCF/D, 28.3 Million M^3/Day). For the SSR version of this model, this represents 62 engine / compressor units and for the HSR model, this represents 31 units[1]. Our compressor lubricant flow rates were derived from the actual unit rates as gathered during the survey. For the Optimal SSR units, these flow rates were largely matching a calculated optimal rate at 2MMft^2/Pint and for the HSR units, the flow rates largely followed OEM specification.

Two units from each type were in break-in, but only one due to recent maintenance; the other three units were found left in break-in past some historical maintenance event. For break-in rate calculations, we used a 1.5x multiplier from the optimized baseline rate.

Lubrication delivery rates were normalized from the unit data and found to be as follows:

	Slow speed Optimal	**Slow Speed @ Break-in**	**TriCip**	**High speed As-found**	**Slow speed Engine**
Delivery Rate (Pint/Mile/MSCFD)[2]	0.001143667	0.0017155	0.000130689	0.001964528	0.005778833
% of SSR optimal	100%	150%	11%	172%	505%
Pipeline usage (Pints/Day)	1143.7	1715.5	130.7	1964.5	5778.8
Pipeline usage (Gallons/Day)	143.0	214.4	16.3	245.6	722.4

Figure 1 - Normalized delivery rates and model pipeline consumption, by unit type

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[1] The model input data arrived at 0.0619 miles / unit / BSCFD for SSR and 0.0301 miles / unit / BSCFD for HSR compressors. The HSR units tend to have higher per unit horsepower and the HSR pipeline operates at approximately 40% higher pressure than the older SSR based pipeline.

[2] See page 99 for metric versions of these tables. Imperial units only shown within the text for brevity

From there, we then applied some standard figures from pipeline operators we surveyed for the paper. Unit utilization of 91%, SSR Unit carryover of 70%, HSR unit carryover of 50%[3], and per gallon oil costs of $9.00[4] for all fluids other than TriCip where that cost of $45.00 was used.

	SSR Optimal	**SSR Break-in**	**TriCip**	**HSR As-found**	**SSR Engine**
Pipeline usage (Gallons/Year)	47,484	71,225	5,426	81,565	239,930
Oil Cost ($/Year)	$427,353	$641,029	$244,172	$734,083	$2,159,369
Carryover into pipeline (Gallons/Year)	33,239	49,858	3,798	40,782	-

Figure 2 - Model pipeline annual consumption and purchase cost by unit type

Fluid disposal

Every bit of oil consumed by the compressors is lost, in that it is injected into the gas stream, collected and disposed of and not reused. This is the most easily quantifiable direct cost of lubricating compressors. There are two primary places this oil ends up – inside the compressor station in knockouts, pulsation vessels, scrubbers, and filters – or outside the station in drips or flushed during cleaning pig runs. Typically, the oil will be mixed with condensate, water and other natural gas liquids and disposed of in bulk. Our survey indicated that this waste stream, if not identified as containing any hazardous materials, costs in the $0.60 - $1.50 / gallon range to dispose of. This liquid is dewatered and then recycled or otherwise refined, processed, or burned as fuel.

This model pipeline is in transmission service; after dehydration and other gas processing, so most of the fluid disposed at this stage will be compressor lube oil. This liquid remains in the gas

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[3] 50% was used for HSR units as opposed to 70% as HSR units tend to be in newer facilities with more attention paid to reducing carryover via better filtration, discharge side scrubbers, etc.
[4] 2022 US Dollars, wherever dollars are referenced throughout this paper

stream after compression and ends up in the pipeline where it separates out from the gas over time. It is recovered during cleaning pig runs performed prior to In Line Inspection (ILI) pig runs, and collected in pipeline drips, slug catchers, and compressor station inlet filtration.

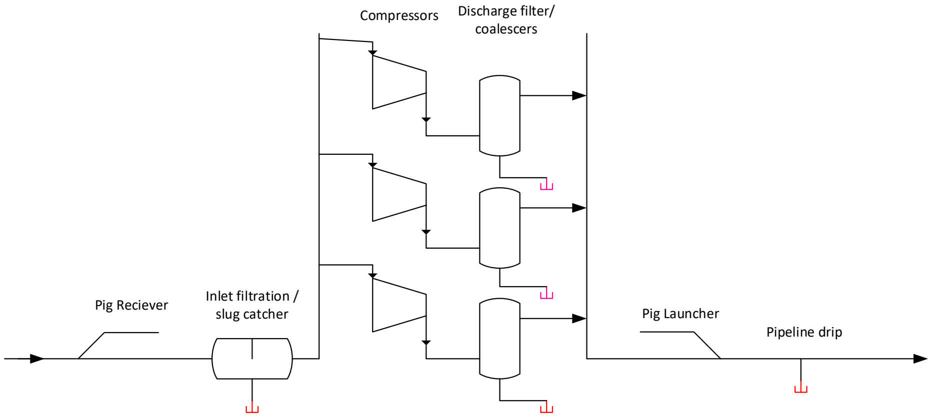


Figure 3 - Simplified pipeline diagram showing liquid disposal points in red

Most of the fluid introduced from compression is collected in one of these automated bulk methods and is relatively inexpensive to dispose of. However, there are occasions where the collected waste is considered hazardous which increases the disposal cost dramatically. Hazards found in pipeline waste may be environmental hazards such as PCBs, chemical hazards like H2S, or radioactive hazards like NORMS (Naturally Occurring Radioactive Materials). Our survey indicated that while rare, classification of pipeline waste as hazardous could increase the cost up to as much as $1800 / gallon. For our model, we averaged these various cost levels out by frequency of probability to arrive at a weighted average disposal cost of $4.88 / gallon.

	SSR Optimal	**SSR Break-in**	**TriCip**	**HSR As-found**	**SSR Engine**
Pipeline Disposal Cost ($/Year)	$162,183	$243,275	$18,533	$198,993	-
Total Disposal cost ($/year)	$231,691	$347,536	$26,476	$397,985	-

Figure 4 - Model pipeline annual fluid disposal costs by unit type

There are several interesting things that this exercise uncovers. First is that even though they are higher speed and can move more volume of gas per unit, HSR compressors tend to consume

72% more oil than SSR machines, even when normalized by flow and distance. This is eclipsed by the high oil consumption of the SSR engines, which is 5x the rate of the compressor consumption but does not impact downstream operations as it is burned in the power cylinders. The emissions impact should be considered, which will be discussed later in this paper. While surveying industry professionals, we attempted to obtain data related to type, frequency, and cost of regular lubrication related maintenance items. Regularly experienced damage or unexpected outages were on this list as well; however, getting reliable data on these types of events is extremely difficult. Despite these difficulties, we recorded several cases illustrating the kind of problems encountered as a result of excess lubricant in the pipeline.

Case Analysis

Cooper W330 – Over-lubrication leads to Power piston failure and cylinder damage.

Background: 6 Months after a complete rebuild, an inspection revealed that all 10 new W330 power cylinders had signs of damage. The operator fully disassembled the engine and found excessive carbon build-up on the inside of the power liners, exhaust elbows, exhaust manifold, and the inlet of both the left and right turbos. This carbon buildup caused extreme wear on all 10 power pistons which were out of spec, rendering them useless due to the damage.

Figure 5 - A power cylinder scored by carbon buildup

Failure Mode: Excessive carbon buildup occurred on the piston rings between the engine pistons and cylinder liner. The carbon caused excessive wear to the pistons, wearing through the coating, leaving one liner scored and out-of-spec. The 2 turbochargers had a large amount of carbon build up as well but were still within specifications.

Figure 6 - Power cylinder port detail

Subsequent analysis revealed that the lubrication system, which was not addressed during the engine overhaul, was delivering approximately 27% more lubricant than the optimum rate as determined by an OEM horsepower calculation. This increased quantity of lubricant is what led to the build-up of carbon.

Pre-lubrication practices may have contributed to this failure as well. A pre-lube system is designed to deliver lubricant to the engine prior to start-up to ensure that the cylinders and rings are well lubricated after a potential lengthy downtime. In an electric driven lubrication system, it is just a matter of activating the motor for a set number of cycles. In a lubrication system that is driven by an auxiliary shaft, a separate air or electric driven pump is required, which can deliver oil at a much faster rate than the engine shaft driven pumps. Frequently, this rate is not properly controlled and much more oil is delivered than is needed. When there are multiple starts, this problem amplifies and can result in significant quantities of oil being delivered, adding to the carbon issue, and even fouling spark plugs.

Impact: The quantifiable impact of replacing 10 pistons and one power liner is $90,317 in parts alone. Because the contractor was onsite pulling the cylinders already, there was not an additional expense to do the work, but it very well could have been as much or more than the parts expense. The total cost to clean the turbos was $30,000.

Additional impacts to this failure that we were unable quantify are downtime, lost throughput, station staff time onsite, administrative time, and the significant headaches associated with any failure.

Figure 7- Turbocharger carbon contamination

Resolution: The cylinder lubrication system that was overlooked during overhaul was inspected and addressed. Several divider blocks were replaced, damaged tubing was repaired, and preventative maintenance was performed on the system. Lube rates were recalculated, and best practices for engine pre-lubrication were applied, including added logic to pre-lube / startup cycles to skip engine pre-lube if the engine had recently shutdown or had repeated attempts to start. This prevents unnecessarily flooding power cylinders and consequent buildup of carbon from the burned lube oil.

Lubrication impacts to discharge / suction coalescer filters, collection volume from a pipeline drip

Background: After repeated coalescer filter element failures and a “near miss” incident at a turbine inlet, a pipeline operator went to lengths to identify and eliminate the source of fluid in a pipeline segment. This operator has a turbine downstream of reciprocating compression and experienced an automated shutdown at the turbine inlet due to alarms on the suction side filtration. Upon inspection, the suction filtration was found to be overwhelmed and several elements had collapsed. While the turbine itself was not directly impacted, an investigation was conducted to determine and rectify the source of the fluid.

Impact: Data was collected from the primary drip after the compressor station discharge, located approximately ½ mile outside the station fence. Fluid collection volume over time was loosely correlated with compressor consumption. Collected fluid chemically matched the compressor cylinder lube oil. While not all the fluid was lube oil, it made up the bulk of the fluid volume collected at this drip. Station discharge coalescing filters were also found to have some collapsed elements.

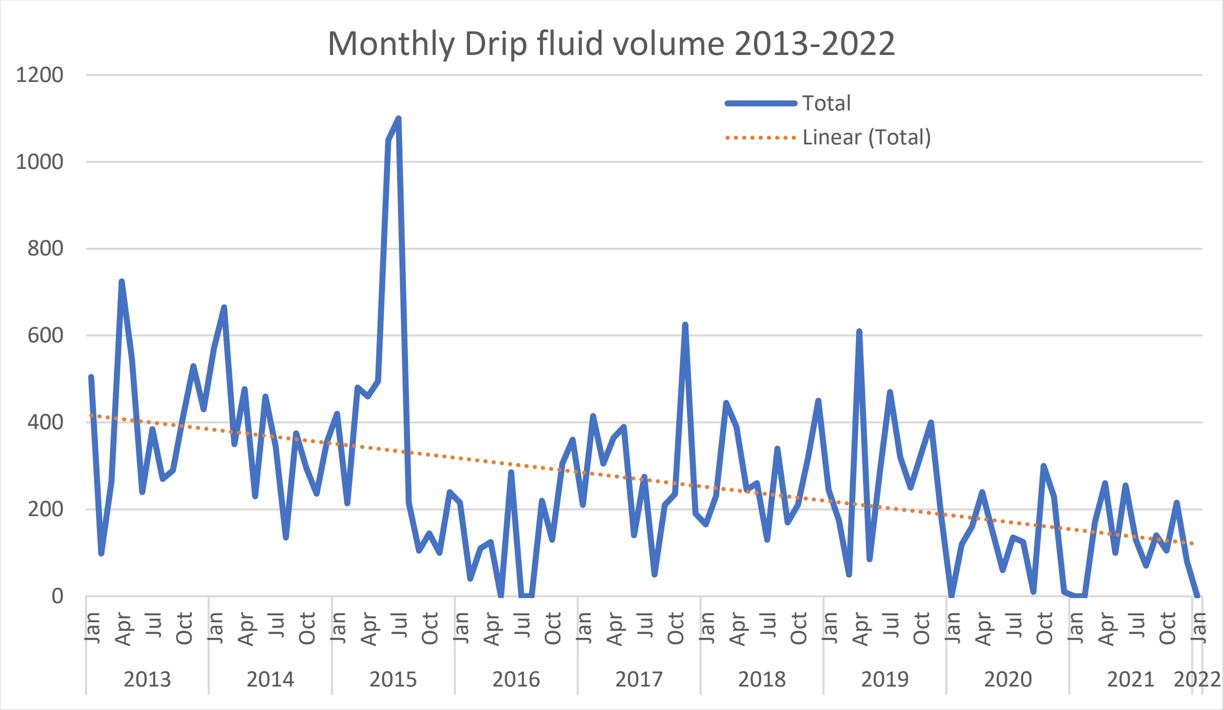


Figure 8 - Monthly fluid collected from a pipeline drip near a compressor station discharge

Resolution: The compressor discharge coalescer filters were immediately changed (late 2015) to a different type that is less likely to foul from liquids, and a very rapid change in the drop fluid volume was observed. However, over time this volume began to increase again, indicating that either the filters lost their effectiveness, or fluid that passed through the filters began to accumulate again.

In 2018 a project was undertaken to replace the filter coalescers at the compressor discharge and at the same time, reduce the lubricant delivery rates.

By mid-2019 both items had been implemented, with compressor oil consumption dropping from ~650 gallons / month to ~40 gallons / month. Continued monitoring of the drip shows decreasing collection volumes. The 2013-2015 average monthly fluid volume from the drip was 395 gallons, the 2016-2018 average was 238 gallons, and the 2019-2021 average was 180 gallons.

That represents a 54% drop in collected fluids, and a reduced risk of incidents at the downstream station. The cost of implementation in this case was approximately $350k and was managed through planned outages. This was a relatively minor impact in comparison to a potential incident resulting in turbine damage that could easily eclipse the seven figure mark in addition to the downtime associated with repairing the compressor.

4x GMWA-8 – Lube rate optimization leads to significant cost reduction

Figure 9 - GMWA8-2 engine

Background: Over the course of one year and 3 incremental steps with inspections, lubrication rates were reduced by 30% leading to increased reliability and reduced maintenance. At each inspection interval, conditions were favorable to continue reducing rates. At the halfway point, lubrication system components needed to be replaced to continue the reduction. This is an important point – many lubrication systems as designed cannot reliably deliver the optimum rate because they were designed to deliver the correct flow ratio at a higher rate. As rates decrease, smaller pumps are required because improperly sized lubrication pumps can short stroke and fail, divider block ratios need to be changed to guarantee proper flow to packing, and divider block sizes need to be reduced to maintain a proper interval between cycles. Age and condition of the existing lubrication system are also factors to consider prior to starting a lubrication rate optimization program because the effects of faulty components are increased at lower delivery rates.

Impact: This project took place 25 years ago and was covered in a presentation at the GMC. Since then, these units have averaged about 5000 hours/year, and have had very few maintenance issues and have zero carbon build-up. The lubricant savings have been approximately 1761 gallons/year for a total of 44,025 gallons saved. Assuming a 25-year average of $6/gallon for compressor lubricant that ends up with a total savings of $264,150. That may not seem like much but consider the cost to remove carbon buildup on a regular basis. Typically, two people can clean one cylinder per day which equals 128 man-hours to remove carbon from one 8-

cylinder engine. If this is a yearly event for all four units, then that would equate to 12,800-man hours over the past 25 years.

Intercooler cleaning required due to excessive turbocharger pre-lube

Background: Engine performance analysis found that a 2SLB (2 Stroke Lean Burn) integral engine / compressor unit was running at reduced horsepower. An inspection found that the intercooler was fouled with oil and dust, reducing flow through the intercooler.

Impact: The engine was removed from service and incurred a cost of $30K labor and materials to remove, clean, and reinstall the intercooler. This resulted a 10–12 day unplanned outage for that compression capacity. A source of the oil was not found during the process, however a subsequent inspection found that the problem had resurfaced. The intercooler was cleaned again, resulting in another 7-day outage, and the source of the oil was determined to be the turbocharger pre-lube cycle.

The turbocharger pre-lube was being run for the entire crankcase pre-lube cycle – nearly 10 minutes. There was not a properly sized pressure relief valve on the turbocharger lube line, resulting in excess pressure being injected into the labyrinth seal, which flooded the engine inlet. In addition, during turbocharger jet assist an improperly plumbed air pilot valve was closing the seal oil outlet even further flooding the engine air inlet manifold.

Resolution: A properly sized and pressure rated relief valve was installed to maintain seal oil pressure and prevent flooding. The air pilot valve plumbing was corrected. The engine pre-lube / startup sequence was modified, and the intercooler was inspected for the presence of oil after several startups to ensure that the seal was not flooding the engine inlet.

Metering Station Contamination – Fouled Regulators

Figure 10 - Gas meter plate, saturated with oil

Background: Pipeline liquids contaminated a metering station at a customer tap. The downstream customer reported issues with a contaminated supply. Metering station equipment was fouled with liquids that were determined to largely be compressor lubricant. Analysis of upstream compressors revealed inconsistent adherence to specified rates and several stations were using significantly more lubricant than suggested.

Impact: Undisclosed end user equipment was affected. The pipeline operator had significant costs associated with cleaning up the metering station. Additionally, lubrication practices had to be addressed and changed at upstream stations.

Resolution: Once the station was cleaned up, new lubrication practices were adopted, and compressor lubrication rates were optimized. A subsequent inspection revealed no fouling at the metering station. This is direct evidence that compressor over-lubrication is a source of liquids contamination not only impacts pipeline operations, but that it also impacts pipeline customers.

Figure 11 - Pipeline gas meter

Additional Impacts - Lost Throughput

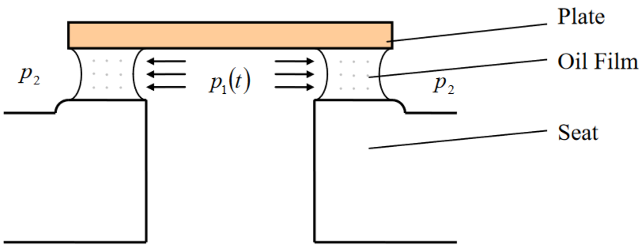
Figure 12 - Cleaning pig saturated with oil

Pipeline restrictions can happen for a variety of reasons. In the hilly eastern states, the pipeline elevation could be compared to a sine wave. Valleys create low points in pipes, and this creates an excellent spot for liquids to collect. Those liquids restrict the flow of gas, requiring more power to move the same volume. Pipeline operators determine capacity by rated horsepower. If restrictions reduce the amount of work that horsepower can accomplish, then this may well be a source of lost and unaccounted for gas. The whole system ran at rated HP but did not deliver rated throughput.

Plaque also contributes to pipeline restrictions as it builds up on the walls of the pipe. These plaques have numerous components and lubricant is one of them. Lubricant has a surface tension that allows it to stick to the wall of the pipe, and that tension also enables other contaminants to stick to it. Over time this build-up can create a slight reduction in the diameter of the pipe. Quantifying these factors is beyond the scope of this paper. It would certainly require an in-depth and detailed analysis, but the authors feel it is significant enough to mention.

Figure 13 – Pipeline flow meter plate with clogged orifices due to precipitated plaque

Additional Impacts – Valve Stiction



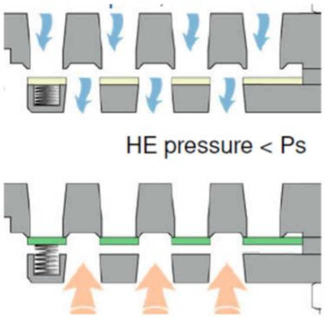


Figure 14 - Valve stiction illustrations [2]

Valve Stiction also reduces the efficiency of pipeline compressors by “causing over-compression/over-expansion inside the cylinder while the discharge/suction valve remains closed.” [2] Stiction is typically discussed as a problem in the context of high-speed compressors because higher speeds require faster valve cycles, meaning that the delay in valve opening has a more obvious impact. However, stiction is still present in slow speed compressors whenever there is a film of oil present on the valves. Timothy C. Allison, Ph.D. and Klaus Brun, Ph.D. wrote in their previously presented GMC paper *Oil Stiction in Compressor Valves: Modeling and Mitigation*, that based on their study, plate impact velocities increase by 230% when stiction is present, [2]. This indicates that when excess lubricant coats the valve components, the engine needs to work harder to generate enough pressure to overcome the stiction. Not only does it take more energy to move the gas, but it also takes more gas to generate that energy. This also reduces the life of the valves, meaning more expense and downtime in the future. In their paper, Allison and Brun review the extensive literature available to search for a way to model the stiction force between two parallel surfaces separated by an oil film. The models they discussed were difficult to put into practice because the models are very sensitive to initial oil film thickness which has great variability from cycle to cycle and is extremely difficult to measure.

These factors – pipeline restrictions, plaque precipitation and valve stiction are complex and difficult to quantify. Beyond just their mention in this paper, we suggest them for future research. Coming up with a working model to predict lost throughput from these factors may well be worth the time and expense.

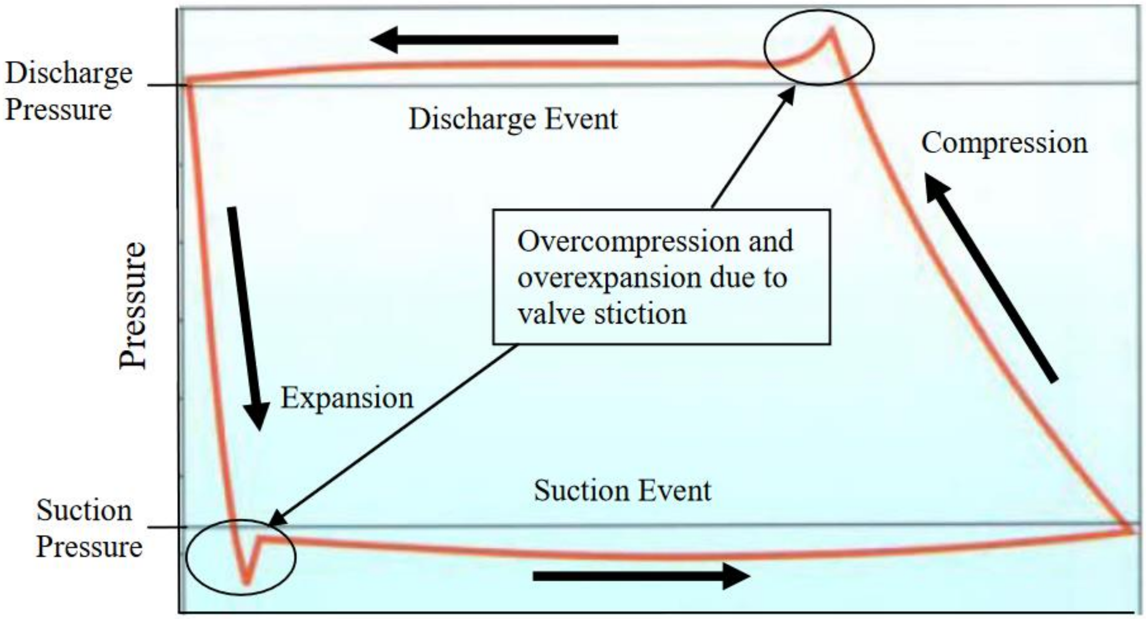


Figure 15 - Example PV diagram with valve stiction [2]

The Climate Impact of Over-lubrication

ESG (environmental, social, governance) is an ever-increasing focus globally, especially in the energy sector, where we are tasked with keeping houses warm and lights on while also being charged with the task of reducing emissions. There are promising technologies in development that could help with this reduction in the future, but none are ready to deploy. Solar and wind make up a larger part of the energy mix each year but have their own impacts and problems. The opportunities for new hydropower are limited by terrain and ecosystem preservation efforts. Hydrogen seems promising, but most of the hydrogen today is made using steam methane reformation at a considerable cost in terms of efficiency and emissions. Making hydrogen a viable alternative fuel will require either capturing the emissions from the steam reformation process, or using wind, solar, nuclear, or other lower emission energy to power electrolysis. Both processes add significant expense and reduce efficiency further. Increasing the challenge of using hydrogen as a fuel is the difficulty transporting it vs other fuels. Once these new means of creating hydrogen are truly viable, it will likely make the most sense to replace the significant quantities of hydrogen currently being used for things like fertilizer production and industrial processes before using it for a fuel. This leaves natural gas as one of the best near-term alternatives to help reduce emissions from energy production. One thing we can do is make sure that we do everything in our power to minimize our emissions while keeping the lights on around the world.

The industry is making great efforts to reduce emissions where possible. Methane emissions from pipeline and packing leaks are being greatly improved with new technologies in sealing and detection. Stack emissions from combustion are harder to solve. There is always a certain amount of slip in combustion and clean burn technologies are helping with that. NOx emissions can be greatly reduced using emissions systems with catalysts. Another primary emission from our industry is CO2. CO2 itself does not have a high global warming potential, but it persists for a long time in the atmosphere. CO2 also serves as the baseline in our system for understanding emissions. The term CO2E, means CO2 equivalent. All greenhouse gasses are assigned a CO2E that is their equivalent GWP (global warming potential) relative to carbon. In this way CO2 acts like a penny in a financial system. Methane has a CO2E of 28 (100-year GWP) and NOx has a CO2E of 290 (100-year GWP).

The two primary GHG impacts of over-lubrication in our industry are via combustion emissions and via the carbon cost of the lubricant. Many natural gas fired engines have catalysts installed in their exhaust systems to remove harmful emissions. It is not as common for engines like the GMVHs in our model pipeline, but some 2 stroke lean burn engines do as well, and it is possible that more will do so in the future. Excessive lubricant damages catalysts. According to a paper presented to the GMC in 2016, “one cubic foot of nonselective catalytic reduction (NSCR) catalyst has on the order of 55 football fields of internal surface area,” [3]. This surface area consists of tiny “nano-scale” pores, that are easily fouled by contaminants. These contaminants prevent the catalyst from removing emissions. The authors state that lubricant is one of the primary contaminants. It contributes to catalyst fouling via both ash and carbon byproducts from the lubricant that burns in the power cylinder, [3]. It stands to reason that the greater the amount of lubricant, the more fouling will occur. This is yet another reason that it is critical to control the amount of lubricant used for power cylinder lubrication. High speed separable compressors all have catalyst, but these engines do not have force feed lubrication. Over-lubrication occurs in them when the rings have excessive wear causing more lubricant to enter from the crank case, [3].

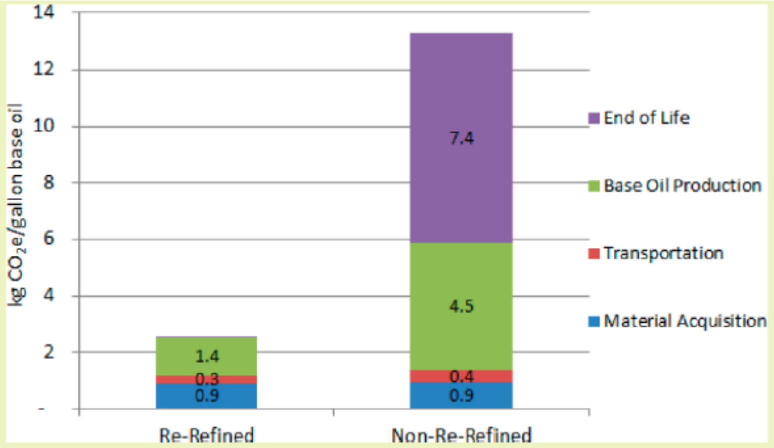


Figure 16 - CO2e values for lube oil

In addition to reducing the efficiency of the catalyst, there are direct emissions from burning the lubricant itself. To accurately calculate what those emissions are, a different life cycle analysis would need to be produced for each lubricant because base oils and additives vary greatly. To create a simplified model, we look at an average base oil and omit the additives which could contribute to the impact. A typical base oil has a carbon cost of 13.2 kg/gal if it is burned, [4], which in the case of power cylinder lubrication is what happens. There is small portion of the lubricant that does not burn and ends up either fouling the catalyst or the exhaust and stack. This amount is very hard to quantify, so for simplicity's sake, we assume that it is all burned.

The carbon footprint of compressor cylinder lubricant is a bit harder to pin down because the end of life is not always apparent. The lubricant is typically collected by a contractor who does not necessarily report the disposal method. It is likely that a significant amount of it is burned, and the impact is about the same as burning it up in power cylinders. In cases where it can be re-refined, that impact is significantly lower as shown in the chart above. The table below shows the relative CO2 emissions for the different lube rate scenarios modeled in our pipeline. Compared to the overall stack emissions from this pipeline, these emissions are not major. There are more impactful ways for pipelines to reduce emissions than lubrication optimization, but lubrication optimization also has significant cost benefits. The environmental benefits add to an already compelling case.

	SSR Optimal	**SSR Break-in**	**TriCip**	**HSR As-found**	**SSR Engine**
Emissions, CO2 Equivalent from oil use (KG / Year)	626,784	940,175	71,624	1,076,654	3,167,075

Figure 17 – Model pipeline CO2e emissions from compressor oil consumption

Solving Over-lubrication

The cases discussed here reveal a need to address potential concerns before they become issues. Much of the solution is to simply prevent oil consumption; if you don't put oil in the pipeline in the first place, you don't have to take it back out later. Perhaps the easiest thing to fix is ensuring that break-in schedules are followed. A regular audit of lubrication system delivery rates compared with calculated target rates will help to catch units left in break-in. Implementing a smart system that indexes rates to operating conditions allows for automated rate adjustment to normal rates after break-in. Some locations have also had success with eliminating break-in altogether, but this should be approached with consultation with the wear material supplier. Another item is to implement a rate reduction program. Often OEM rates can be reduced if the lubrication system components are in good condition and gas conditions are monitored closely. This is done through a scheduled step down and inspection process. [5] This is time consuming but can achieve good results with minimal capital expenditure. Another path would be to implement technology permitting compressor operation with minimal oil consumption such as TriCip.

Once oil is in the pipeline, removing it can be challenging. Even if compressor delivery rates are turned down the effects may take some time to be measurable. Attention to separation equipment, coalescing filter element types, and automated condition monitoring such as in the compressor drip analysis case previously covered in this paper significantly help to avoid damage and downtime. In that case a costly repair was avoided due to automated alarms, and then the root of the problem was fixed via scheduled outages.

In 2SLB engines, care can be taken to ensure that lubrication systems are maintained, regularly tested, and lubrication rates are properly calculated per OEM specifications. Not all engine types use the same calculation, even if they are from the same manufacturer and have the same horsepower rating so take care to ensure the proper rate is being applied. Pre-lube cycles should be checked as well to ensure that they are not unnecessarily flooding the power cylinders on startup. Additionally, if the engine load can vary, implementing a variable speed lubrication system indexed to brake horsepower can help with carbon buildup during lightly loaded run time.

Conclusion

The exercise undertaken for this paper shows that collecting operational data and building an idea model from that data is relatively straightforward and shows some interesting differences between types of compressor units. At the same time, gathering solid data regarding issues encountered as a result of excess engine and compressor lubrication in order to include a normalized “trouble cost” is very difficult. While the authors uncovered a great number of anecdotal case studies and had industry professionals very willing to talk about the oil related issues they encounter, it appears that those cases are not regularly tracked in a systematic way. This is consistent across essentially every operation we surveyed. Each organization has a different way of accounting for unexpected maintenance, downtime, and unplanned events. Thus, while we were able to calculate that the actual cost of compressor lube oil is nearly 1.5x the purchase price when accounting for disposal, and there is a measurable environmental impact, the actual end cost of compressor lubricant (and the effects of inadvertently over applying lubricant) are quite hard to nail down.

We loosely estimate that the additional costs of over lubrication are an additional 50-150% of the cost of the initial fluid purchase price, which would give us an “over lubrication cost multiplier” of 2-3x the purchase price for each extra gallon of fluid used beyond what is required to reliably operate the compressors. A focus on regularly checking flow rates and reducing compressor oil consumption will prevent these additional costs and reduce pipeline operation cost in general.

Metric conversion of model pipeline tables

Figure 1:

	Slow speed Optimal	**Slow Speed @ Break-in**	**TriCip**	**High speed As-found**	**Slow speed Engine**
Delivery Rate (Liter/km/Million M^3/d)	0.01187	0.01781	0.00136	0.02040	0.06000
% of SSR optimal	100%	150%	11%	172%	505%
Pipeline usage (Liters/Day)	644.2	974.9	74.3	1116.3	3283.9

Figure 2:

	SSR Optimal	**SSR Break-in**	**TriCip**	**HSR As-found**	**SSR Engine**
Pipeline usage (Liters/Year)	179,746	269615	20539	308757.112	908233.849
Oil Cost ($/Year)	$427,353	$641,029	$244,172	$734,083	$2,159,369
Carryover into pipeline (Liters/Year)	125,823	188,733	14,376	154,376	-

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