

Troubleshooting Contamination In Gas Compression

> Advanced identification, removal systems can reduce downtime

BY DAVID B. ENGEL AND SCOTT WILLIAMS

Gas compression systems are a vital yet delicate part of any gas plant, transmission line or refinery. In simple terms, gas compressors raise the pressure of gas in a stream by reducing the gas volume. Heat is created and the gas stream is generally cooled before use or transport. There are many different types of compressors, but all work by imparting energy to the gas, reducing its volume, heating the stream and increasing pressure.

This process creates changes in conditions for the gas stream, and contaminates to some extent the compressed gas stream with aerosolized micron and sub-micron lubrication oils and other residues. These small-sized contaminants can create significant challenges in the downstream units such as metering stations and gas processing plants.

Only a small number of compression systems have the necessary means to adequately remove contaminants in the outlet compressed gas stream. As natural gas and other feedstocks become more and more contaminated (from shale formations, for example) there is a fundamental need for accurate gas contamination testing and high-efficiency separation systems for contaminant removal.

Causes and effects

Compressor failures and downstream problems can be caused by a variety of mechanisms, and every compression system must be monitored, inspected and maintained with a holistic approach.

Dissolved contaminants in the gaseous phase or in water entrained in the gas can settle in the system during

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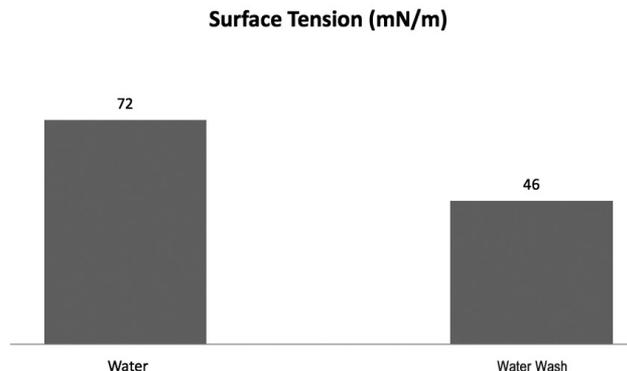
compression, leading to fouling and corrosion, reduced throughput and eventually, failure. Suspended solids in the gas stream can cause similar effects in addition to erosion.

One of the most common and difficult challenges in gas compression, however, is dealing with lubrication oils and additives injected within the system.

Lubrication oils typically contain 90% base oil (most often petroleum fractions, called mineral oils) and about 10% additives for various functions. Additives deliver reduced friction and wear, increased viscosity, improved viscosity index, and resistance to corrosion, oxidation, aging and contamination.

Most additives, however, have surfactant properties causing a number of downstream problems such as foaming. Base oil, usually a heavy hydrocarbon, generally causes many detrimental effects downstream. These are related to the agglomeration of the heavy hydrocarbon with solid particles in the gas stream forming larger residues.

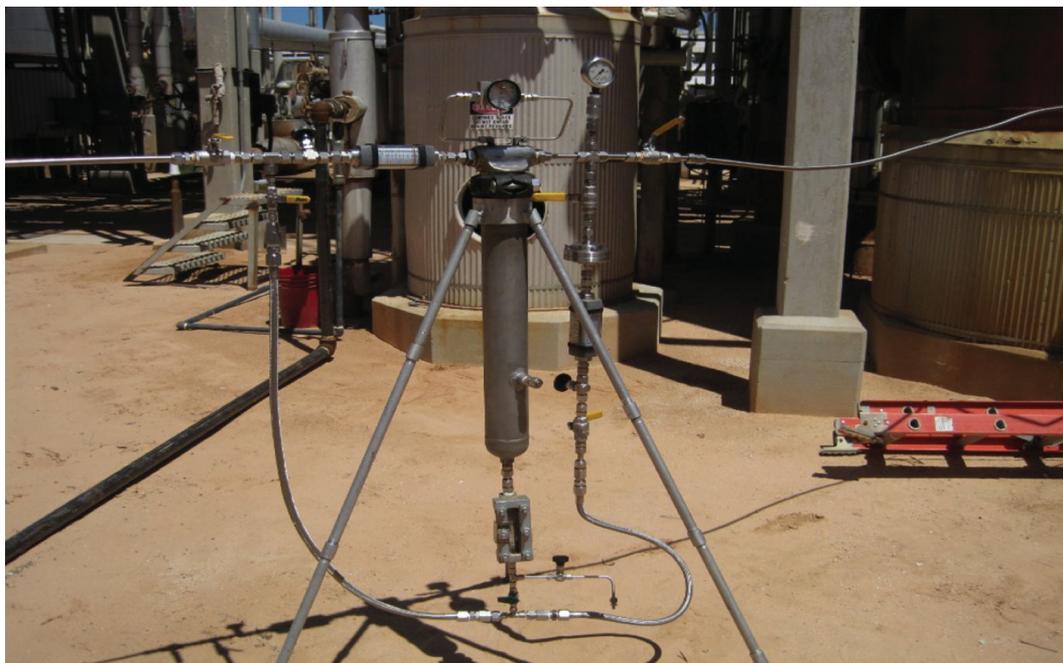
This material can cause deposition and fouling in many gas lines and downstream equipment including pumps, compressors and metering equipment. These contaminants are responsible for inaccurate gas metering that generates considerable revenue losses.



■ Figure 1. This bar graph shows the effect of the surface tension of water when contacted with lubrication oil.

To illustrate this point, Figure 1 shows the change in surface tension of pure water when contacted with lubrication oil. The decrease in surface tension from 72 millinewtons per

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■ Figure 2. The photo shows the setup of the GASCO test system for a compressed gas stream.

meter (mN/m) to 46 mN/m is a clear indication of the surfactant properties of water soluble additives in the lubrication oil.

The decrease in surface tension leads to an increase in entrained water and dissolved contaminants downstream as separation equipment loses liquid removal efficiency. Poor liquid removal efficiency leads to downstream issues including foaming, fouling and corrosion in addition to process solvent losses and performance decay.

Compression systems in gas plants, refineries, transmission lines, chemical plants and other industrial settings are an integral part of the operation, and without the system pressure created, the process often cannot operate.

Compression systems in refinery fluid catalytic cracking units are generally responsible for a large percentage of a refinery's output, and failure can lead to complete refinery shutdowns causing tens of millions of dollars in lost revenue.

Natural gas compressor stations are responsible for the transportation of raw and processed natural gas, and supply the pressure needed for gas plant operations.

Adequate compression system protection is thus an extremely important aspect of successful plant operation, as compressor failure and also contamination breakthrough have enormous consequences.

Contamination characterization

The first step in compressor protection is in understanding the nature of contamination in the stream, and gas testing is a vital piece of any troubleshooting protocol. Contamination in the feed gas contributes to many issues both in the compression system and downstream, so the identification of contaminant ingress should be performed in almost every case.

Suspended solids, water and dissolved contaminants, additives and other liquid contaminants such as heavy hydrocarbons should be monitored and quantified, and a suitable feed separation system can be put in place if necessary.

Feed contamination can play a major role in compression system challenges and is often cited as the main cause of process problems.

Plant operators and engineers often overlook the injection of lubrication oils and additives in the compressor itself, however, and neglect to identify those sources of contaminant ingress. In cases where lube oils and additives are of concern, downstream effects such as foaming and fouling are often observed, and testing of the gas stream at the outlet of the compressor should be performed.

Liquid contamination in gas streams is one of the most common and detrimental challenges. In compression systems, lubrication oils and additives, heavy hydrocarbons and water all cause harmful downstream effects, and must be identified and quantified before a removal solution can be developed.

The testing for liquids in gas streams is performed quantitatively using a gas-liquid super coalescer (GASCO) test system (Figure 2). The system consists of a high-pressure housing that contains the coalescer element.

The gas flow to or from the compressor is routed from the high-pressure point into the housing and sent to the low pressure outlet. As gas flows across the multilayer media element, the liquids are intercepted, coalesced and drained from the element.

At the bottom of the test system there is a sight glass with an inner reservoir to accommodate the drained liquids. The sight glass is calibrated to measure liquids accumulation. Liquids can then be removed from the system by means of a needle valve.



The separated liquids can then be analyzed for their composition and concentration, and a better understanding of process challenges can be gained.

The nucleus of the test is the coalescing element. The test elements are designed using specialized media formulations. The efficiency of the elements is rated at 99.98% for liquid droplets down to 0.1 μm in size. The elements also have the latitude for the separation of liquids with a broad spectrum of polarities and viscosities.

With advanced testing for liquid contaminants using the GASCO system coupled with suspended solids characterization, a thorough contamination characterization can be completed and utilized to select the most effective compressor protection plan.

In any case where feed contamination is present, it is always advisable to locate the source. Oftentimes a capital investment can be avoided by identifying and correcting issues upstream. If at all possible, avenues for reducing feed contamination should be investigated before an investment is made in process protection.

In gas compression, liquid contamination from injected lube oils and additives is always present, and source removal is not an option. In this case, process protection is a must.

Many systems have been designed and implemented for liquids removal, but few have success in completely or even adequately removing the contamination.

Separation of liquid contaminants in gas streams is usually carried out using demisters (also known as knock-out drums) equipped with a metal coalescing pad element or vane pack installed near or at the outlet of the vessel.

Demister systems are typically vertical in orientation; however, they are only adequate for removing large diameter contaminant droplet sizes. In fact, these separators were originally designed for bulk liquids removal (also called slug catchers).

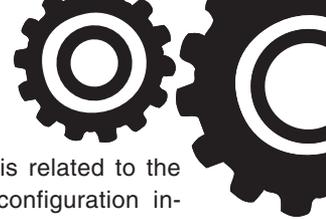
These devices are not designed for solids separation (usually done by a wet scrubber or a particle filter) with the exception of cyclonic systems that can remove large solid particles and some larger liquid droplets.

Only a small number of compression systems have the necessary means to adequately separate the lubrication oil liquids in the gas stream caused by injection at the compressor itself.

As far as contamination in gas streams, the most prevalent and difficult contaminants to separate are submicron liquid aerosols. These are finely divided liquid droplets with diameters ranging from less than 0.1 μm to a few hundred microns.

Droplet sizes below 1 μm are the most difficult to remove due to the absence of a specific separation mechanism that yields high removal efficiency. The typical aerosol distribution in gas streams is primarily in the submicron

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range. Larger droplets tend to not be as persistent, as they are likely to be separated by gravity. Larger droplets can shatter due to the shear forces surrounding the droplet surface with certain deficient vessel design features.

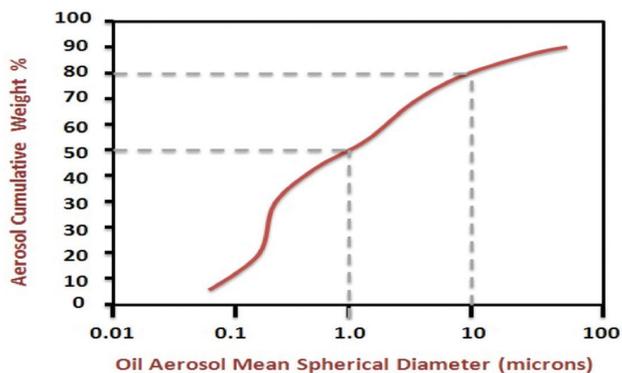
When large droplets shatter, progressively smaller droplets are created until the distribution is stabilized by the balance of energy distribution, gravitational settling and shear.

Other devices such as mesh pads, vane packs and cyclones are ineffective because they are not able to capture the small and most penetrating submicron aerosols. Vane packs are especially ineffective when dealing with submicron liquid aerosols since the small droplets do not have enough momentum to properly contact the vane surface. Most small droplets are just carried with the stream.

Interfacial layers in many vane packs and some mesh pads are one cause of inefficiencies, and companies have mitigated this by using different designs (double and single pockets). Their efficiencies can be enhanced somewhat for larger liquid droplets, low liquid loadings and gas velocities within certain limits.

Although mesh pads suffer similar inefficiencies, their removal rate is somewhat better due to the higher surface area, but these devices are prone to particle fouling.

Today, the technology of choice for high-efficiency removal of submicron aerosols in gas streams is built around specially formulated microfiber media. Vane packs, cyclones and mesh pads should only be considered for larger liquid aerosols with droplet sizes well above 10 μm . Nevertheless, these devices are good for bulk liquids removal (slug catchers) or as a pre-separation process prior to a more efficient stage downstream.



■ Figure 3. This shows a typical liquid aerosol size distribution at the outlet of a compressed gas stream.

As indicated in Figure 3, about 50%/weight (w/w basis) of all liquid contaminants in a gas stream area are smaller than 1 μm (aerosols), and 80%/w are smaller than 10 μm . Hence, most of the approaches to separating liquid contamination in gas streams using demisters with mesh pads, vane packs or certain horizontal filter-separators display rather low efficiencies at removing submicron aerosols (% weight).

The reason for the lack of efficiency is related to the aerosol droplet size distribution, flow configuration inside the separator and the mechanism of liquid droplet interception. In other words, the separation media is not capable of intercepting and coalescing submicron liquid droplets (followed by liquids unloading in order to enable proper high-efficiency separation).

Most aerosol contaminants break out of the system almost intact. The vessel configuration is also critical even if the separation media is appropriate. The internal flow direction and gas routing inside the separator could be a source of significant inefficiencies. Additionally, poor vessel designs can actually shatter liquid aerosols into smaller sizes, adding more difficulty to an already challenging separation process.

Most gas separation systems currently installed in refineries and gas plants as well as existing designs for future projects are usually not very appropriate for the separation of submicron liquid droplets in gas streams. These systems are conventional separation technologies for bulk removal. The efficiency decreases dramatically as particles become smaller than 10 μm in diameter.

Mesh pads suffer from flooding when excessive liquids are introduced and the mesh becomes saturated with liquid; this leads to efficiency losses by carry-over. Conventional devices are also prone to solids-fouling by particle deposition at the mesh structure surface, further reducing efficiency and causing considerable maintenance costs and pad failures. Movement of the mesh pad inside the vessel is somewhat common due to the difficulty of properly anchoring these devices to the vessel interior.

Alternative options, such as vane packs, have better mechanical performance and lower differential pressure, but provide inferior separation efficiencies. Even modern developments where improvements are made by the combination of vane packs and mesh pads do not adequately produce the necessary removal efficiency to protect sensitive equipment and processes.

A compressed gas separation for the outlet of compressors is called a “high-efficiency submicron coalescer” equipped with correct instrumentation, valves and specially formulated microfiber coalescing media. High-efficiency submicron coalescers possess the ability to intercept and coalesce submicron aerosols and properly drain the coalesced liquids from the element structure.

As indicated in Figure 3, submicron liquid droplets compose on average more than 50% of the total liquid contaminants in a gas stream. Submicron coalescer devices are carefully designed depending on the flow, pressure, temperature, gas composition and contaminants. They should be installed as closely as possible to the unit or process they are intended to protect.

Typically most correctly designed high efficiency submicron coalescers are capable (in theory) of removing, on

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average, 99.98%+ of all aerosols with diameters between 0.1 to 1.0 μm (and larger) as measured in a laboratory setting. In essence, this is the majority of the liquid aerosol contamination in a gas stream.

These devices should be protected with a suitable particle filter separator (equipped with the correct separation media) in order to extend the online life of the coalescer and to minimize operational costs, as the replacement filter elements for particle separation are much less expensive than coalescing elements.

Correctly designed submicron coalescer vessels have two stages: the bottom section designed to remove bulk liquids, and an upper high efficiency stage for aerosol removal. In certain occasions, the bottom section can be fitted with a mesh pad, vane pack or designed in such a way as to have cyclonic action. The gas then leaves the bottom chamber flowing into the second stage immediately above via the coalescing element's interior.

The gas is then directed across the microfiber coalescing media. The fine aerosols are intercepted, coalesced and drained from the elements by gravity. Like the lower stage, the upper stage has a liquid removal system comprised of a level control and drain valves. The gas exits from the top of the vessel.

Typical campaign times for gas coalescing elements can vary anywhere from six months to up to two years depending on the amount of solids entering the coalescing stage as well as additive presence.

It is important to point out that many fabricators advertise systems capable of removing submicron liquid aerosols. Most do not correlate these claims and expectations with actual performance. Only a small number of companies possess the proper technology to supply submicron gas-liquid coalescers.

Case study

A South American oil and gas company subcontracts external companies to operate a number of compression stations throughout the country. It is critical to be able to rely on specific standards for compressed gas and compressed gas quality.

At these compressor stations, the gas is compressed and invariably there is injection of lubrication oils into the gas stream (originating from the compressors themselves). Testing of the compressed gas was performed in order to understand the level of contamination in the gas stream and whether the gas coalescing system's design for its removal was effective.

Training on gas coalescing and filtration was first performed with the objective of setting the fundamental un-

derstanding of the phenomenon and to lead into testing of the gas stream.

The gas was then tested using the GASCO system to determine both the concentration of lubrication oil present in the form of aerosols and the concentration of lubrication oils penetrating the coalescer equipment. The GASCO system is often used by Nexo Solutions to determine contamination in gas streams in many industrial settings.

The amount of lubrication oil collected in the GASCO system during testing was not enough to cause accumulation in the sight glass at the bottom of the test system. Hence, the lubrication oil was not visible.

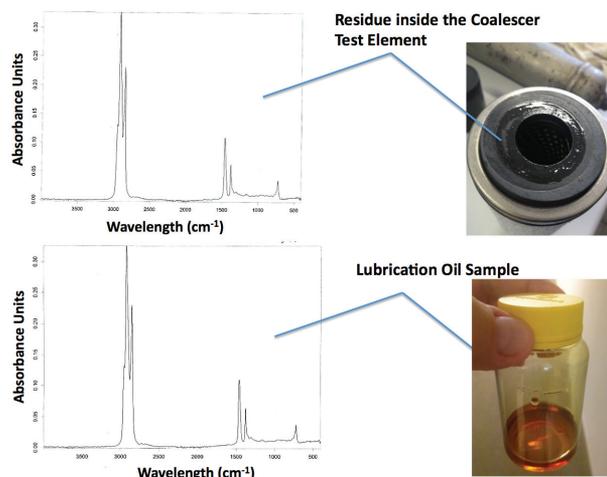


Figure 4. These photos and associated IR spectra illustrate residue from the GASCO test element.

However, upon inspection of the test elements, it was clearly identified that lubrication oil was present in the interior of the element. This can be seen in Figure 4 as the end of the test element was inspected and had a considerable amount of lubrication oil residue.

This residue was carefully removed and analyzed using infrared spectroscopy (IR). The IR spectrum (Figure 4) is a match with the sample of lubrication oil supplied by the compression station facility. The spectra of both materials were consistent with the base oil present in lubricants. Lubrication oils are typically high molecular weight hydrocarbons, mainly composed of C and H atoms. Similarly, the spectrum only shows CH_2 , CH_3 and C-C vibrations.

As the amount of lubrication oil was not enough to cause accumulation in the test systems, the contaminant was removed from the coalescing element using a solvent wash. The test element was weighed with the lubri-

Sample Point Parameter	Mass Oil Recovered In Coalescing Element	Time Duration Of Each Test	Lubrication Oil Concentration In The Gas Stream	Lubrication Oil Losses
Outlet Of Compressor	4.8 Grams	25 Hours	0.00598 ppm	5.11 mL
Outlet Of Coalescer	0.4 Grams	22 Hours	0.00056 ppm	0.43 mL
Actual Coalescer Efficiency	91.7%			

Table 1. The lubrication oil concentration in each test point is displayed.



cation oil inside and then after the oil was removed.

The solvent used for removal was hexanes (150 mL). This solvent is also compatible with the test element and will not remove any component from its structure. (Only the lubrication oil is removed.)

The data for the lubrication oil quantity separated in each test run and the actual concentration of lubrication oil in the main gas flow is shown in Table 1.

From the data acquired by the GAS-CO test system, it was apparent that the efficiency of the installed coalescer is near 92% (in a mass basis). This efficiency is lower than what is normal for a high efficiency submicron liquids coalescer. The total amount of oil present in the compressed gas stream is low.

This low concentration was achieved by the correct operation and maintenance of the compressors themselves. The correct and periodic maintenance of the compressor parts, seals and gaskets are critical in order to prevent release of lubrication oils in the form of aerosols.

The low efficiency in removing aerosol was caused by a few factors, and further investigation can verify the exact causes. The possible causes are:

Incorrect vessel design — The process conditions and flow in the vessel were simulated, and the 42 in. (106 cm) outer diameter size of the installed vessel was found to be larger than required. A vessel with a 36 in. (91 cm) diameter and 19 to 23 coalescing elements, with 4.5 in. (11 cm) diameter and 36 in. (91 cm) length, would have been sufficient.

Gas coalescer vessels have a determined size envelope. A small vessel will have considerable contaminants carry-over caused by the high gas velocity in the vessel interior. An oversized coalescer vessel will not generate the sufficient energy to promote the coalescing process inside the microfibrinous coalescing element structure. This will also cause contamination carryover.

In this particular case, the vessel positioning of the outlet, located below the element line using a baffle plate, was also erroneous. This arrangement is inefficient as the outlet gas inside the vessel needs to change direction many times causing increased velocity and increased carryover possibilities.

New vessel designs have the outlet a minimum of 10 in. (254 cm) above

the element line with no baffle. This ensures only one gas turn direction in the vessel prior to the outlet and also reduces localized high velocity and carryover.

Incorrect maintenance procedures

— To what was understood, the vessel was properly maintained periodically. Pictures of the vessel were taken during

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inspection. This is important for possible future troubleshooting. The vessel interior was not inspected during the visit.

One possible area of importance is correctly inspecting the vessel interior for possible depositions in the support hardware or for any hardware malfunction. This can cause a bypass if residue build-up is not cleared or if the hardware is not properly functional.

Incorrect media — One possible aspect for enhancing the quality of compressed gas by reducing the concentration of lubrication oil is increasing the removal rates and ensuring that the removal rate is not affected by shutdowns and start-ups of the gas flow.

It has been observed that all coalescers lose efficiency when the gas flow is interrupted and resumed at a later time. In Figure 5, this phenomenon is shown comparatively for some of the most common coalescer elements in the marketplace today. Data was obtained during many field tests over the last two years.

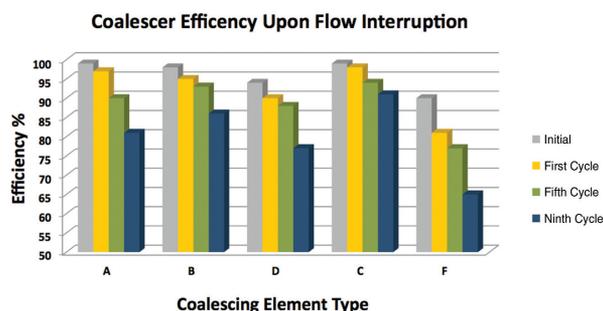


Figure 5. This graph shows the effect of gas flow interruption on different gas-liquid coalescing elements.

Some coalescer elements do not have adequate initial liquids removal efficiency. Only certain coalescing elements show proper aerosol removal, however, in all cases the decay in efficiency upon cycling (shutdown and start-up) is considerable.

The decay in efficiency at the outlet of compressors at cycling operational modes is related to the interaction of the liquids and other contaminants that remain inside the coalescing element with the various fibrous materials. There is likely to be both chemical degradation of the fiber materials and plugging of small pores responsible for small liquids aerosol removal.

From the data in both GASCO tests for aerosol removal and quantification, it was indicated that the compressors are operating correctly with minimal liquids injection into the gas stream. This is primarily due to the age of the equipment (fairly new) and proper maintenance and operational procedures. As the equipment ages and deficient maintenance and operation takes place, the presence of higher lubrication oil concentrations is more common.

The installed gas-liquid coalescer at the outlet of the plant (outlet of air coolers) had a slightly oversized diameter but in this case, did not affect operation or performance of the sys-

tem. The system was simulated and the flow exit velocity and media face velocity were within acceptable parameters. However, the overall efficiency (by mass) was lower than what is acceptable for a compressed gas stream at the outlet of a compressor station.

One of the most likely causes of poor removal efficiency is the degradation of the fibrous material in the coalescing element when stagnant liquid is in its interior or a coalescer element internal with poor efficiency (or maybe a combination of both factors). A possible improvement alternative is to install XC coalescing elements that have materials in their interior specially designed to endure intermittent gas flow (cycling) operations.

Figure 6 shows the variation of efficiency on XC coalescers upon cycling. It can be observed that the efficiency is not affected. In many cases the efficiency remains constant up to the ninth cycle of shutdown and start-up.

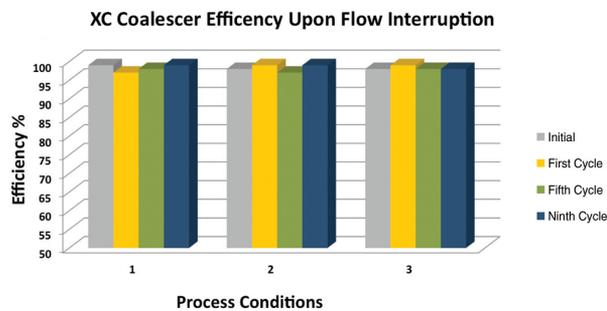


Figure 6. This graph shows the effect of gas flow interruption on the XC gas-liquid coalescing element.

This new technology is critical to ensure that quality compressed gas is delivered to the gas line and that contamination is properly removed in order to minimize inadequate gas metering and further processing in operations downstream.

Conclusions

There are considerable benefits associated with contaminant removal in gas compression systems. Several aspects including gas testing, separation system design, maintenance and media choice must be performed correctly in order to ensure adequate contaminant removal.

Properly designing, operating and maintaining a coalescer separation system will unequivocally provide significant downstream protection. Foaming, fouling, corrosion of process equipment and inadequate gas metering can be expected without proper protection. Contamination in gas streams varies greatly in both type and concentration, and the best solution for each case varies as well. Proper identification and quantification of contaminants including solids, dissolved species and liquids must be accomplished so the correct solution can be designed.

Improving process efficiency and profitability is important to every plant, and taking the right approach to contamination in gas compression systems has fundamental impacts on process stability and economics. **CT2**