

FUNDAMENTALS OF
GAS-LIQUID SEPARATION
WITH A FOCUS ON GAS PROCESSING



FGL-1.0

Abstract

This document focuses on gas-liquid separation in natural gas transmission. Importantly, the fundamentals in this document are not limited to natural gas only and can be applied to the separation of other gases and liquids.

The safe and successful transport of natural gas is tied heavily to two words: contamination control. Whether natural gas is being transferred from the wellhead to the end user for domestic supply, natural gas-fired power plants, or conversion into feedstock to drive the production of plastics, fabrics, pharmaceuticals, and other products, the journey is made possible by contamination control. Liquid, solid, and gas contaminants can form or be introduced into the stream at many points along the gas transmission journey, which creates costly and often-dangerous problems within the overall gas transport system.

This technical report starts off by addressing the importance of liquid separation technology in the journey natural gas takes as it leaves the reservoir and moves through the natural gas transmission system for delivery to final custody transfer. It also discusses the productivity, safety, and cost implications of poor liquid contamination control for operators and the significant challenge submicron aerosol droplets pose to gas processors and end users.

Subsequently, this report illuminates the complex process of submicron droplet removal at the microscale and focuses on key considerations in high-efficiency coalescer design and performance. It also presents common mistakes in gas separation design, specification, and utilization, along with a current field snapshot of submicron aerosol removal driving productivity in the industry.

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PART 1

**Utilizing Gas-Liquid Separation
Technology to Mitigate the Impact
of Liquid Contamination on the
Natural Gas Journey**

Fundamental Barriers to Safe and Efficient Gas Transmission

Two naturally occurring phenomena that disrupt safe and efficient gas transmission include the formation of hydrates, which can plug pipelines and damage equipment, and corrosion within gas transmission pipelines. Additionally, most pipeline corrosion rate failures are a result of electrochemical oxidation of metal piping due to naturally occurring contamination. When acid gases and liquid contaminants in the gas stream combine, the pipe wall can become pitted and the thickness can be degraded, which increases the risks for leaks and explosions.¹

For this reason, pipeline companies often include strict clauses in their contracts to ensure that gas suppliers do not contaminate their pipelines or create circumstances that lead to costly pipeline repair and maintenance, or worse, to possibly lethal outcomes. While specific contract language varies, a typical stipulation is that “gas should be free from objectionable odors, bacteria, solids matter, dust, gums and gum-forming constituents, free liquids, crude oil, and any other substance that might interfere with the merchantability of the gas, cause injury to or interference with the proper operation of the lines, meters, regulators, compressors, processing plants, or applications through which it flows.”²

Pipeline operators also maintain strict specifications for contaminants. The specified limits for a given type of contaminant will vary by pipeline and contract. However, the industry standard for water content is 4-7 pounds per million standard cubic feet (MMSCF). If the gas is slated for conversion into liquids, then the gas needs to be “bone dry.”³ Common acid gas standards for pipeline-quality natural gas typically specify 2-3 mol % CO₂ and 0.25-0.3 grains/100 standard cubic feet (scf) (4.125-4.95 ppm) of H₂S content.⁴

Since safe and efficient gas transmission is so clearly predicated on the removal of contaminants during gas processing, advancements in the field of gas-liquid separation remain of utmost importance to gas process operators.

The Gas Processing Journey

A typical pathway for natural gas as it moves through processing is shown in **Figure 1** (below). This graphic represents a high-level overview of gas transmission from the wellhead to its intended destination and demonstrates the importance of gas-liquid separation along the journey.

With so many individual processes involved, and with contaminants prevalent in the gas stream in a range of forms and sizes, numerous liquid separation technologies are required to adequately address the varying sizes and concentrations of natural gas contaminants.

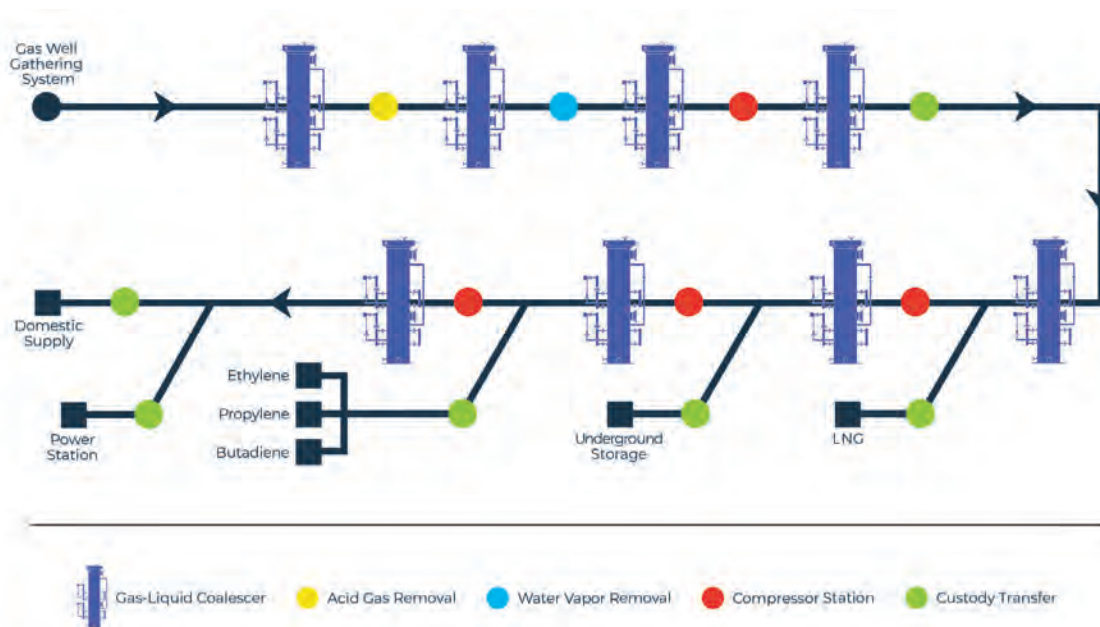


Figure 1
Overview of Gas-Liquid Separation Along the Gas Journey

The Role of Gas Processing Facilities in the Gas Transport Journey

Once natural gas enters the pipeline from the gas well gathering system, the first essential contamination removal steps take place at a gas processing facility to remove acid gases, such as H_2S and CO_2 , and reduce the water content in the gas to meet specifications of the pipeline or downstream process. Examples include conversion to LNG for export or storage, and the conversion to olefins as feedstock for companies who manufacture chemicals, plastics, elastomers, among a long list of other products.

Circumstances vary by region and according to the properties of the extracted gas, although natural gas processing plants typically have an amine solvent system to “scrub” H_2S and CO_2 from natural gas, a removal process often referred to as “gas sweetening.” A second common process involves a dehydration system, such as glycol dehydration or molecular sieve, to remove unwanted water from the gas stream.

Gas processing plants rely heavily on filtration and separation technology not only within these processes, but also to protect these processes from contamination that can create major upsets and

poor performance. It has been well-documented that the most significant cause of contamination in gas processing plants involves contamination in the inlet gas stream. There are many forms of liquid contamination originating from many sources, but the most common contaminant is lubricating oil from compressors. Natural gas is a compressible fluid, and compression is used to create a pressure differential that promotes gas flow down the pipeline from one location to another. Lubricating oils are used to lubricate the pistons in the compressor stations along the transmission pipeline, and these lubricating oils commonly end up in the gas stream.

Le Grange, et al surveyed 399 cases of process failures in amine systems and found that the majority of process failures were related to poor filtration or separation (**Figure 2**).⁵ They reported 107 cases of failure due to amine foaming, 56 (or 52.3%) of which were directly correlated to the presence of foam-promoting contaminants that had originated in the feed gas.

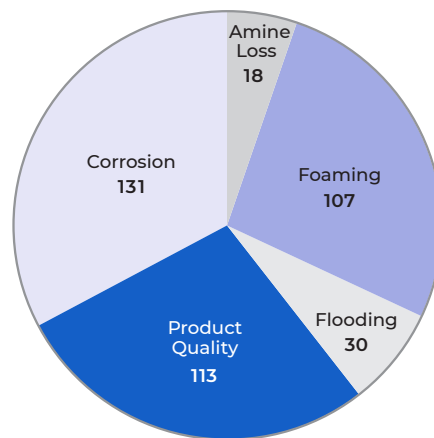


Figure 2
Causes of Process Failures in 399 Amine Systems Surveyed⁵

Because liquid and solid contaminants contribute directly to process challenges such as corrosion, erosion, fouling, and foaming, it is widely accepted that the operational stability of gas “sweetening” plants is largely dependent on the mitigation of contaminants.

Gas-Liquid Separation Technologies – Fit for Purpose

The list of liquid separation technologies from course to fine includes gravity separators, centrifugal separators, vane pack separators, mist eliminators, low-efficiency horizontal filter separators, and high-efficiency coalescers. Each is designed to perform a specific task associated with a particular point in the gas processing journey.

For example, two-phase separators use gravitational forces to control the separation of slugs and large droplets of liquids, including hydrocarbons. However, they are rarely designed to remove droplets smaller than 300 microns in size. As such, two-phase separators are ineffective for high-efficiency separation of submicron aerosols in the gas stream.

Similarly, vertical gas-liquid coalescers are generally not designed to remove slugs of liquids, so inlet slugs of fluid and liquid concentrations beyond rated capacities are outside the scope and design parameters of these types of coalescers. As a practical matter, slugs can damage coalescing elements, as shown in **Figure 3**, reducing their operational life and resulting in the complete bypass of liquid contaminants.



Figure 3
Damaged Coalescing Elements Demonstrating Bypass

Still, each of these liquid separation technologies has its place within an efficient, safe, and profitable gas processing stream. It is important to understand the droplet size of the liquid contaminant so that the most suitable equipment can be selected and designed to remove the contamination from the stream.

Section 7 of the 14th edition of the “GPSA Engineering Data Book” provides guidance regarding the most suitable equipment for various liquid droplet sizes. **Table 1** provides a list of the common gas separation equipment classifications with their corresponding typical minimum removable droplet size.

Type of Gas Separator	Typical Minimum Liquid Droplet Size Removed
Gravity separators	250 μm
Cyclone separators	40 μm
Vane separators	10 μm
Multicyclone or high-efficiency centrifugal separators	5 μm
Mist eliminator pad separators	2 μm
Horizontal filter separators	1-10 μm
High-efficiency coalescers	0.1-0.3 μm

Table 1
General Gas Separator Classification by Minimum Droplet Size Removed

In recent years, as separation technology has advanced, more options in high-efficiency gas-liquid coalescers have become available to operators interested in mitigating the high costs associated with liquid contamination. While the separation fundamentals and equipment design criteria of bulk liquids or larger droplets is very well understood, the separation of submicron aerosol droplets is much more complex and often misunderstood, resulting in improper equipment selection or design.

High-Efficiency Gas-Liquid Coalescers

Common applications for high-efficiency gas-liquid coalescers in natural gas processing include:

- ▶ Protection of costly equipment such as compressors
- ▶ Recovery of discharged compressor lube oils
- ▶ Protection of turbo equipment
- ▶ Protection of low NOx burner nozzles
- ▶ Protection of amine and glycol contactors
- ▶ Liquid recovery on discharge of amine and glycol systems
- ▶ Protection of molecular sieve beds
- ▶ Pipeline hydrate inhibition

The impact of utilizing high-efficiency coalescers on process function and economics is generally quite significant. For instance, reciprocating compressor failure has been shown to be caused by inlet gas contaminants in about 20% of cases.⁶ The removal of contaminants from inlet gas directly improves the reliability of compressors. Utilizing a high-performance gas-liquid coalescer system upstream has been found to offer compressor protection for a two-year period.⁷ Finally, Le Grange et al determined that each individual case of amine system failure identified in their study represented production losses of between \$250,000 and \$250 million per case, representing several billion dollars in total lost revenue.⁸

Sources and Formation Mechanisms of Submicron Aerosol Contamination

As gas travels from the wellhead through pipelines, it encounters process equipment that are designed to function optimally in the absence of contaminants.

Any liquid contamination can be physically altered as it passes through rigorous pipeline environments, metering equipment, or through various parts of process equipment. As a result, it is quite common to find submicron-size aerosols in a gas stream. The key mechanisms for aerosol formation are listed below.

1. Condensation. Condensation is one of the primary processes that introduces submicron contaminants such as water droplets or hydrocarbon condensates into the gas stream. Hydrocarbon dewpoint indicates the temperature at which heavy hydrocarbon components begin to condense out of the gaseous phase when the gas is cooled at constant pressure. With condensation aerosols, the formation of nuclei and condensation growth occur in tandem, and nucleation continues to the extent the gas is supersaturated. The size and scatter of condensation aerosols is dictated by this dynamic.⁹

Aerosol mists resulting from condensation range in size upwards from 0.1 micron, with the actual sizes of entrained droplets being influenced by local gas velocities.¹⁰ As shown in Figure 4, a significant portion of these droplets falls within the submicron range.

Aerosols also exist by way of atomization forming 10-200-micron droplets through mechanical shear, and entrainment or movement of liquid droplets larger than 500 microns.

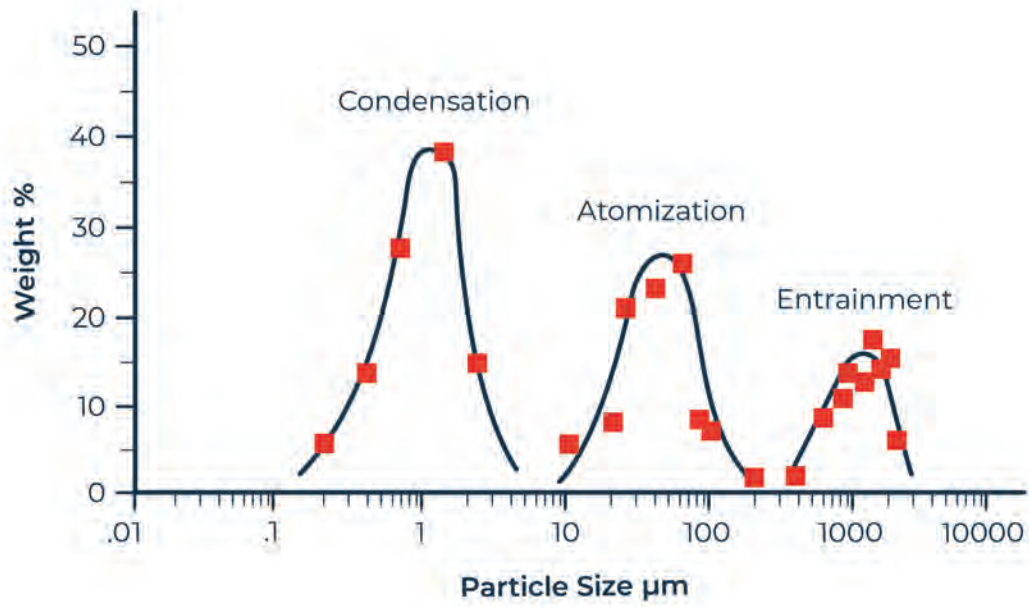


Figure 4
Aerosol Droplet Size by Formation Mechanism¹¹

2. Compressor lube oils. Another significant source of submicron aerosol contamination stems from the use of lube oils in compressor stations. Lube oil can vaporize in contact with hot parts of the compressor and condenses at the outlet. Additionally, rotating components within compressors shear the liquid into submicron-size droplets. These droplets are too small to be removed by the post-compressor lube oil scrubbers. As a result, they are introduced into the gas stream where they subsequently impact downstream equipment and process operations. The cumulative weight percent of aerosol droplet sizes generated by various compressors is illustrated in **Figure 5**. The chart demonstrates that the droplets are predominantly submicron in size, with over 50% less than 0.4 microns in all cases measured.

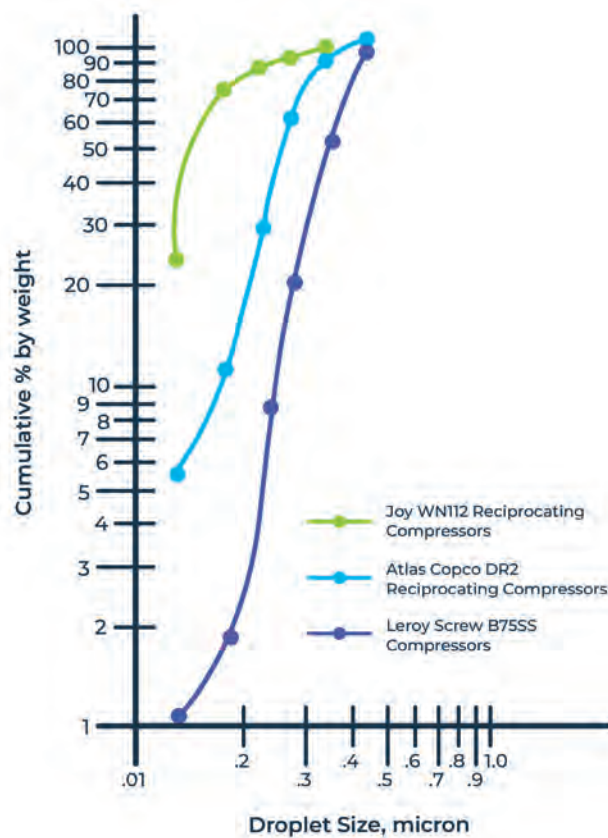


Figure 5
Aerosol Droplet Sizes Generated by Compressor Systems¹²

3. Droplet instability. Droplets can be sheared as they pass through orifices within metering or process equipment that create substantial turbulence, or as they impinge on rough surfaces within pipelines, particularly at bends and turns. Droplet shear is also substantiated by the physics of high-velocity zones within the process and pipeline, wherein the stability of a droplet is related to its critical Weber number. For sub-micron droplets, the Weber number tends to be <1, indicating domination of interfacial and viscous forces relative to inertial. As a result, submicron droplets are typically quite stable and need well-designed equipment to intercept and remove them from the gas stream.

Natural and Artificial Contaminants at Play

As indicated above, submicron aerosol contaminants exist either by way of natural occurrence or are artificially introduced into the stream.

Table 2 lists common natural and artificially introduced liquid contaminants. The size of the aerosol droplets can vary by method of formation, as well as by operating conditions such as pressure, temperature, saturation, and velocities, among others.

Naturally Occurring/ Formed in Process	Artificially Introduced
Condensed water	Compressor lubricating oils
Hydrocarbon condensate	Completion fluids
Brine	Corrosion inhibitors
Organic acids	Hydrate inhibitors
Amino acids	Pipeline friction reducers
Heavy hydrocarbon	Solvent carryover (amine or glycol)
Polymerized hydrocarbon	Oxygen and H ₂ S scavengers

Table 2
Common Liquid Contaminants in Gas Process Streams

Regardless of the origin of the contamination, strict liquid contamination management with a correctly designed, high-efficiency separation system can eliminate well-documented and costly problems for gas processing plants such as these:

- ▶ Solvent foaming
- ▶ Solvent losses due to carryover
- ▶ Equipment fouling
- ▶ Increased corrosion rates of piping and equipment due to under-deposit corrosion
- ▶ Ineffective stripping efficiencies resulting in off-spec gas
- ▶ Poor heat transfer efficiency/Increased energy consumption
- ▶ Increased maintenance costs
- ▶ Frequent downtime
- ▶ Unreliable operations

PART 2

**Managing Liquid Contamination
Along the Natural Gas Journey
with High-efficiency Gas-Liquid
Coalescing Technology**

Understanding the Mechanism of High-efficiency Gas-Liquid Coalescence

Before designing a gas-liquid coalescer system, one must first understand how aerosols flow through the process stream and appreciate what makes their removal so challenging.

Aerosol droplet removal is not a single-step operation. Rather, it is a complex process requiring several critical steps, each allowing little room for error. As such, optimized separation and removal of submicron aerosols naturally depend on the correct design of multiple components, including pre-filtration, bulk liquid knockout, and high-efficiency coalescing elements.

The process of coalescence involves three primary stages (**Figure 5**), each of which contributes to the overall efficiency of aerosol droplet removal.

- ▶ Droplet capture
- ▶ Droplet growth
- ▶ Coalesced liquid drainage

Several models of coalescence have been proposed to date based on the various theories of droplet capture, growth, and drainage.

- ▶ Davies and Jeffreys model
- ▶ Hazlett model
- ▶ Vinson and Churchill model
- ▶ Spielman and Goren model
- ▶ Sherony and Kintner model¹³

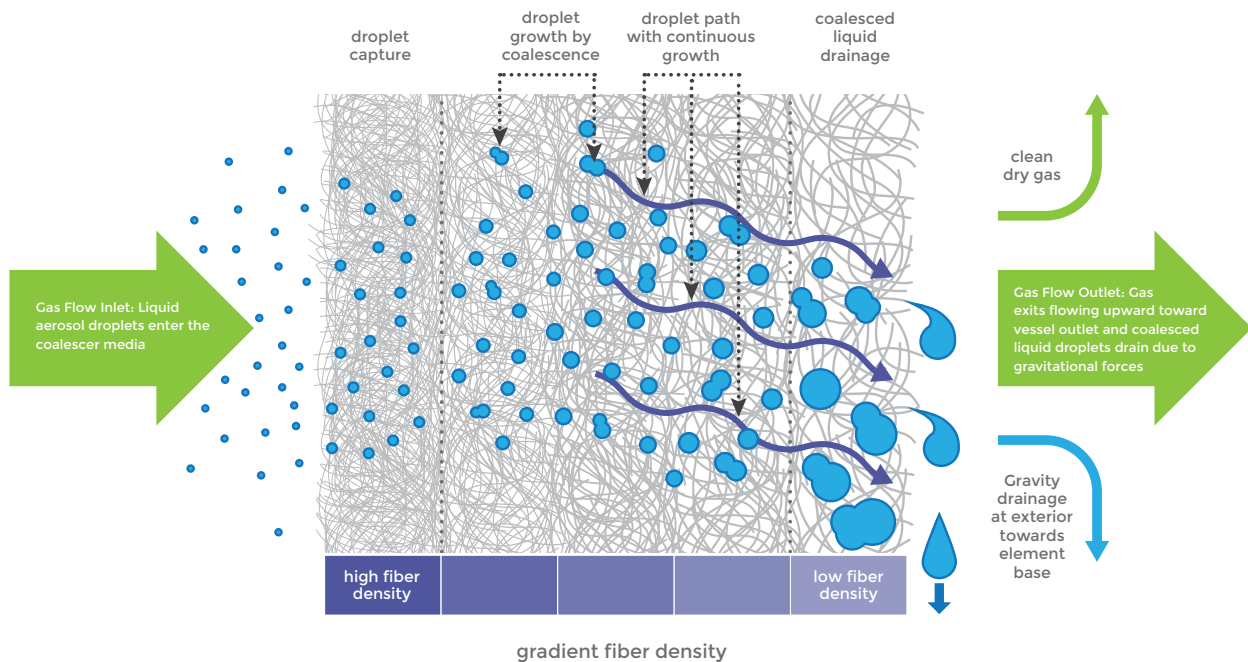


Figure 5
Three Stages of Coalescence

Droplet capture on filter media proceeds by way of the following primary mechanisms¹⁴, as illustrated in **Figure 6**.

1. Diffusion deposition (0.001 to 0.2 μm). The trajectories of individual small droplets do not coincide with the streamlines of the fluid because of Brownian motion. With decreasing droplet size, the intensity of Brownian motion increases, as does the intensity of diffusion deposition.

2. Direct interception (0.2 to 2 μm). Under this mechanism, a droplet is intercepted as it approaches the collecting surface at a distance equal to its radius.

3. Inertial impaction ($>2 \mu\text{m}$). The presence of a body in the flowing fluid results in a curvature of the streamlines in proximity to the body. Because of their inertia, individual droplets do not follow the curved streamlines but are projected onto the body and may deposit there. The intensity of this mechanism increases with increasing droplet size and velocity of flow.

4. Gravitational deposition ($>25 \mu\text{m}$). Individual droplets have a certain settling velocity due to gravity. Consequently, the droplets deviate from fluid streamlines and may contact a fiber.

5. Electrostatic deposition. Both droplets and fibers in the filter typically carry electric charges. Deposition of droplets on the fibers may take place because of the forces acting between charges or induced forces.

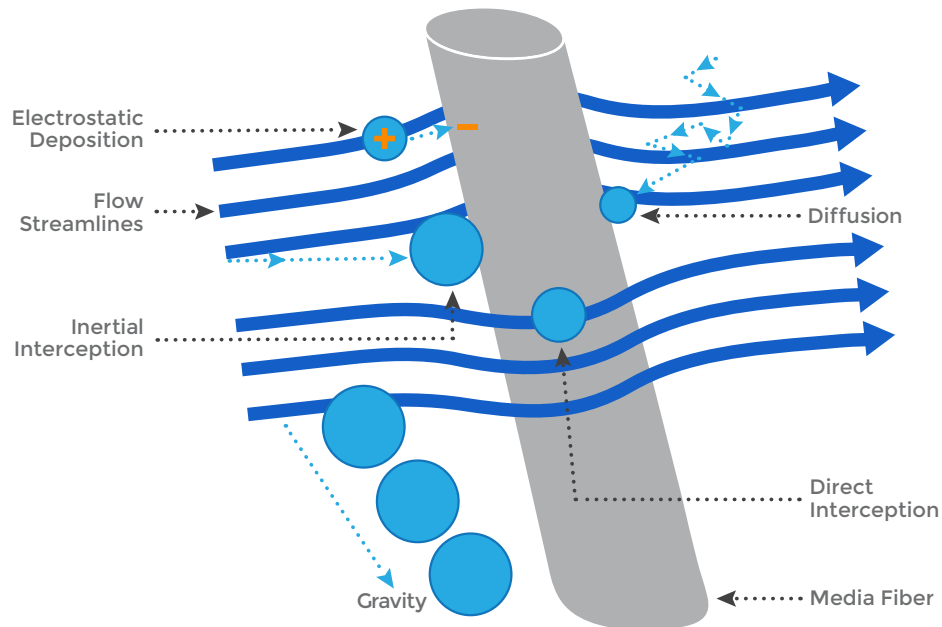


Figure 6
Primary Mechanisms of Droplet Capture on a Fiber

Aerosols formed by condensation of a vapor into a liquid are the smallest and most difficult to remove contaminants, having a size distribution in the range of 0.2 to 5 μm . Aerosol droplets in this range are not captured by only one mechanism, and collection is governed by mechanisms that depend on the physical diameter of the particle. Other factors such as fiber size, solidity, and face velocity also play an important role.

According to Hinds¹⁵, the minimum efficiency occurs in the 0.05-0.5 micron range since no capture mechanism is dominant in this range. Therefore, total efficiency is dependent on multiple mechanisms of diffusion, interception, and impaction, as illustrated in **Figure 7**.

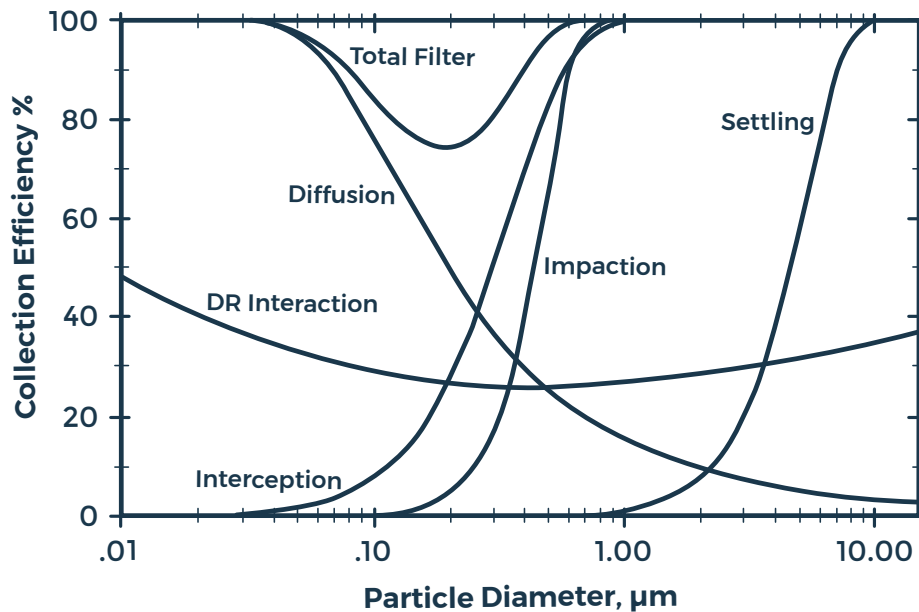


Figure 7
Mechanism Removal Efficiency Defined by Droplet Sizes

Single fiber efficiency theory predicts that the efficiency of droplet capture and thereby coalescence increases as the fiber diameter scales down to the range of incoming droplet sizes.¹⁶ Subsequent research has shown that fiber diameter by itself may not improve droplet coalescence, possibly due to aerodynamic slip effects, and that the fibers need to have surface characteristics with moderate droplet adhesion forces.¹⁷ The most penetrating particle size (MPPS) generally is expected to be lower when the fiber size is reduced and/or packing density is increased.

Once the droplets are captured on the fibers (see **Figure 8**), they are afforded enough residence time to contact other droplets on the fiber surface, sometimes forming a film of liquid. This relates to a characteristic referred to as “wettability.”

As viscous drag forces increase and exceed the adhesion forces, they move the grown droplets further into the coalescer fiber bed. The pore structure of the coalescer medium increases with depth for this reason: to accommodate larger droplets. The process of droplet growth and transport continues until the droplets reach the drainage layer, importantly with sizes large enough to drain by gravity while overcoming the drag force of the gas. Consequently, the effect of gas drag is minimized on the coalesced droplets, which otherwise could lead to re-entrainment of the droplets back into the gas.

It should be noted that the effectiveness of fiber wettability, droplet growth, and liquid drainage can be impacted using advanced surface energy modification techniques to control the surface tension and wettability between the liquid contaminant and the fiber surface. These techniques play a critical role in the proper design of high-efficiency coalescer cartridges.

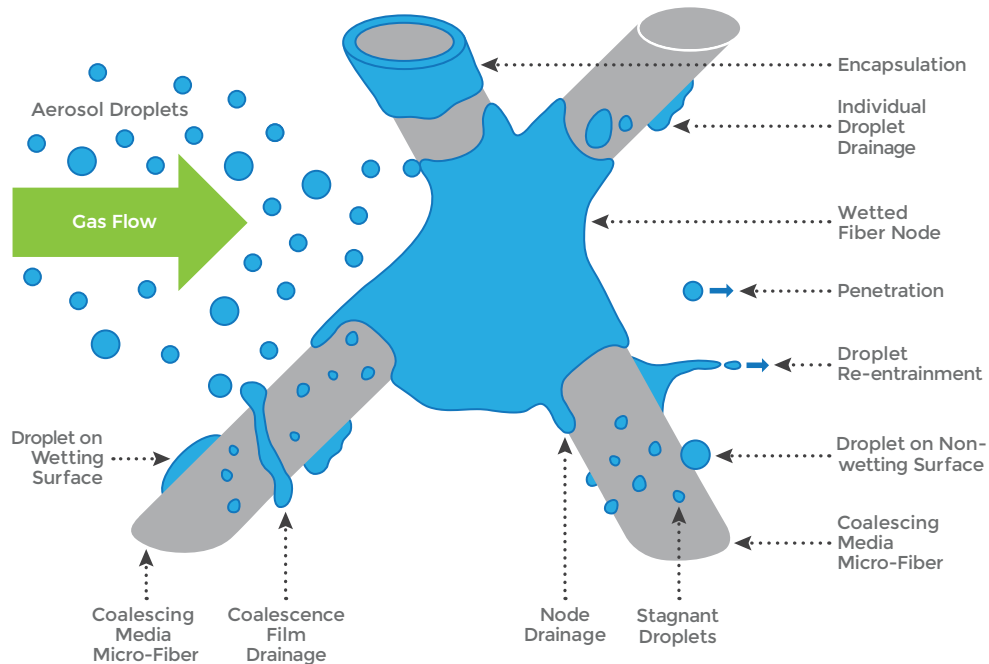


Figure 8
Depiction of Droplet-Fiber Interactions

Gas-Liquid Coalescer Design Considerations

1. Managing Velocity Profiles

Managing the hydraulic forces within the gas coalescer housing is critical to performance. Important velocities include nozzle velocity, media face velocity, velocity through the drainage layer, and the annular velocity between coalescer elements. The recommended annular gas velocity and media face velocity is generally chosen depending on the application, gas/liquid physical properties, and the design features of the coalescer vessel. Proper spacing of coalescer elements is critical to managing the annular velocity.

Velocity specifications are driven by several factors.

- ▶ The effectiveness of bulk knockout of dispersed liquids upstream of the coalescer
- ▶ Liquid droplet sizes entering the coalescer
- ▶ Specific properties of the dispersed droplets (e.g., density and viscosity, among others)
- ▶ Maintenance of coalescer media properties (e.g., surface wettability, pore sizes, fiber diameter, among others)
- ▶ The effectiveness of the drainage layer in channeling coalesced liquid, and in turn preventing or minimizing re-entrainment with gas
- ▶ The desired efficiency of droplet separation (i.e., a higher-than-desired velocity generally results in lower separation efficiency)

2. Media Surface Area

The surface area of a coalescer element has more to do with efficiency than with pressure differential. As such, surface area is a control parameter should be optimized for a given application.

As the gas approaches a high-efficiency coalescer media surface, having the droplets contact the fibers at the media surface allows for the entire depth of the media to be available for droplet growth. In this regard, having an increased surface area would be integral to better performance and capacity increases where the liquid loading allows. Additionally, a higher media surface area provides for a lower media face velocity, which is tied to the residence time of droplets within the media depth and enhances the coalescence process.

If the effective surface area of a coalescer cartridge becomes plugged with solid contaminants, the “open area” is reduced, and the media face velocity is increased, which in turn can reduce droplet removal efficiency. Although pre-filtration is always recommended to reduce the impact of solid contaminants on a high-efficiency gas-liquid separator, it is seldom implemented. Pleated, high surface area cartridges provide significantly more surface area and porosity for solids than non-pleated “depth-style” cartridges while reducing the possibility of increased face velocities due to pore plugging. They extend coalescer life and promote reliable droplet removal efficiency throughout the life of the coalescing element.

3. Liquid Loading Capacity

The design of a coalescer element is based not only on critical gas flow velocities and differential pressure, but also on the liquid loading, which is the amount of liquid in the gas stream challenging the elements. A low liquid loading calls for a careful choice of surface area, while a high liquid loading demands that the element is rated to handle a high liquid capacity with good drainage features. Including a first-stage bulk liquid knockout is crucial to a well-designed, high-efficiency gas-liquid separator. If a significant portion of the liquid loading is in the submicron range and the bulk knockout is ineffective, then the vessel diameter and the number of elements might need to be increased.

If an element is challenged with a liquid load higher than it can handle, each step of the coalescence process – drop capture, growth, and drainage – is impaired. Consequently, incoming droplets in the feed gas can make their way through the elements without capture/growth. Additionally, captured or grown droplets can potentially be carried out with the gas outlet in a process commonly referred to as “droplet re-entrainment.”

4. Force Balance (Hydraulic Drag vs. Gravity)

Because it would be detrimental for a grown droplet to break down or get carried over by the gas (re-entrainment), it is paramount that each stage of coalescence be controlled within guided parameters. A droplet exiting the media should generally be large enough to drain by gravity and not be carried forward by drag force (**Figure 9**). The size of coalesced droplets directly influences the drag and gravity forces acting on them, and droplet shape dictates the adhesion force in play with the media surface at the points of contact.

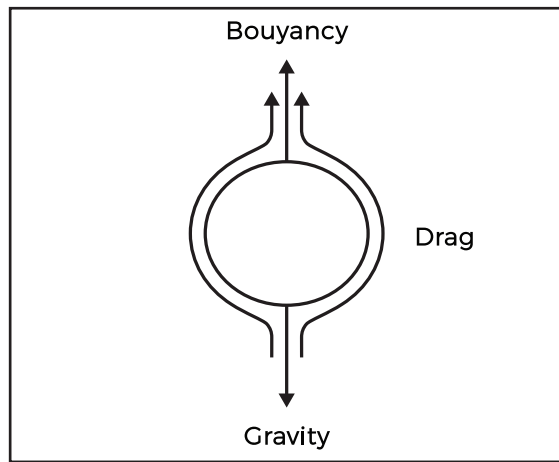


Figure 9
Forces on a Liquid Droplet¹⁸

The force balance equations below can be used to determine annular velocities. To avoid re-entrainment, it is imperative that the gravitational force on the coalesced droplets is greater than the upward drag force.

Drag force can be calculated using:

$$F_d = C_d (\pi r^2) \rho_g V^2 / 2$$

Gravitational force can be calculated using:

$$F_g = 4/3 \pi r^3 (\rho_l - \rho_g) g$$

where

F_d = force (drag)

F_g = force (gravity)

ρ_g = density (gas)

ρ_l = density (liquid)

g = gravitational constant

r = radius of droplet

C_d = drag coefficient

5. Pre-treatment

Several components go towards a well-designed gas-liquid separator: pre-filtration, bulk liquid knockout, high-efficiency coalescing elements, and the design of the separator vessel.

Liquid contaminants in the gas stream can potentially interact with any solids to present further challenges by changing the nature and physical property of the resulting contaminant. This has the potential to undermine the intended equipment design and performance. As a result, pre-filtration of gas streams for solids separation is highly recommended, where possible.

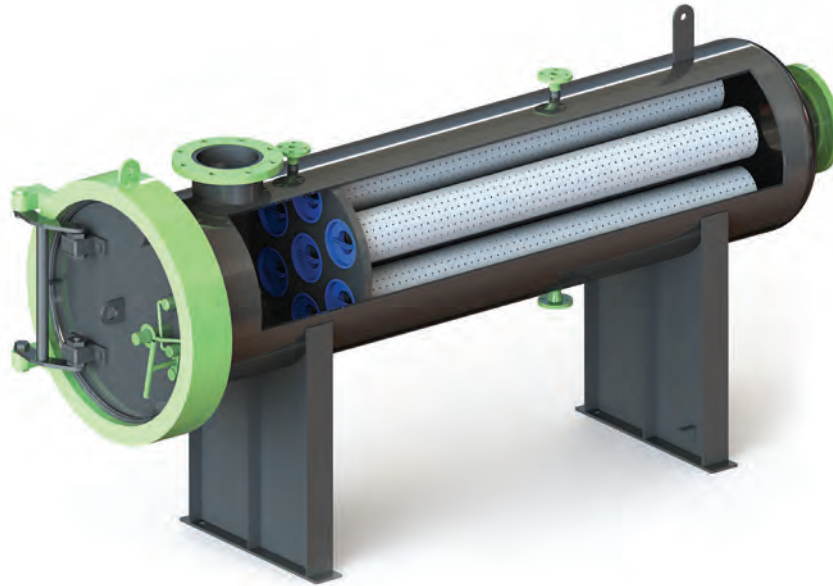


Figure 10
FTC Tersus Series High-Efficiency Gas-Solids Filter Vessel

Figure 10 shows a high-efficiency gas-solids filter vessel.

The efficiency of a given separator is dependent on the incoming liquid load; likewise, the efficiency of a coalescer element is dependent on the use (or otherwise) of an upstream bulk knockout device. Certain separators combine multiple features in one device. Several designs of separators are available.²⁰ The liquid droplet sizes to be removed can generally be matched to the respective gas separator selections.²¹ The mist concentration serviced by gas-liquid separators typically ranges from hundreds of ppm up to 10% by volume. Where possible, it is recommended to have a bulk knockout separator that can easily separate out a substantial portion of the liquid to reduce the load on the coalescer, thereby allowing it to handle the challenging droplets more effectively.

6. Proper Media, Cartridge, and Vessel Design

Very often, the performance of a coalescer filter media and element is intrinsically tied to the design features of the coalescer vessel into which these elements are placed.

To maximize liquid removal by coalescer elements, it is critical to force droplets to travel through correctly designed flow regimes with well-defined flow parameters within the separation zones, as the gas traverses through nozzles and tube sheet orifices. The droplets enlarged by the coalescer elements need to be separated without being sheared or carried over. Accordingly, the liquid needs a clear path out of the elements with minimal influence by gas flow. In this regard, vessel design plays a significant role in maximizing coalescer element performance.

Figure 11 shows a correctly designed high-efficiency gas-liquid coalescer vessel.

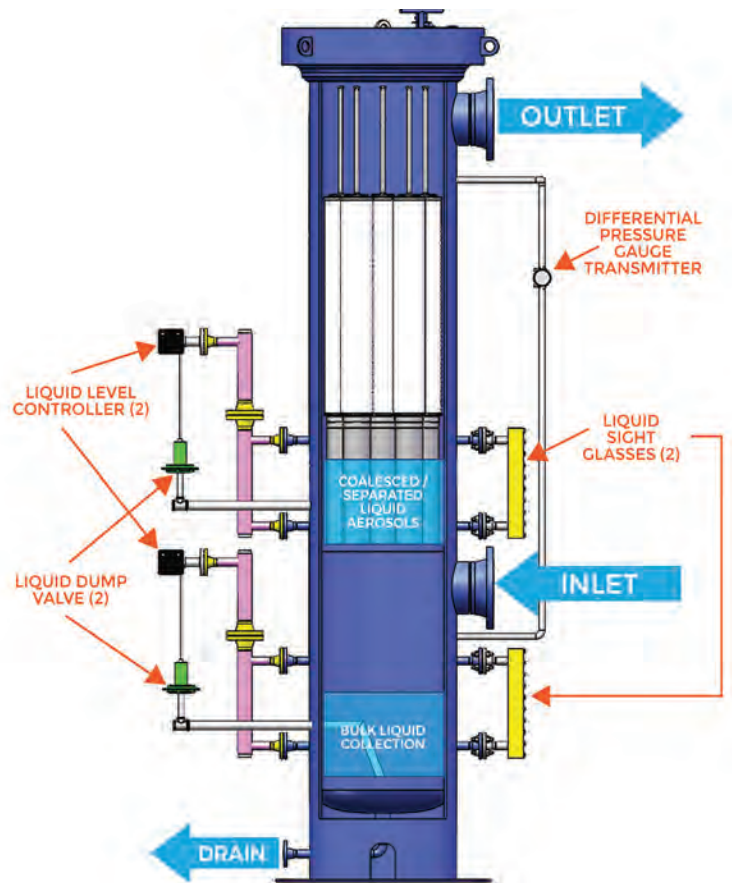


Figure 11
FTC Cyphon Series High-efficiency Gas Coalescer Vessel

With so many variables affecting droplet capture, coalescence, and drainage, proper design of the coalescer vessel is essential to reliable performance.

It is strongly recommended for coalescer vessel design to conform to the guidelines listed below.

- ▶ The gas flow path should be inside to outside.
- ▶ The vessel should be in a vertical orientation to avoid entrainment of separated liquid droplets. When submicron droplet removal is required, horizontal configurations should be avoided to eliminate possible droplet re-entrainment from high-velocity zones or from liquid draining onto the usable surface area of other elements.
- ▶ Instrumentation port locations are critical to avoid removed liquid level from building up above the liquid accumulation zone. If these liquids get too close to the gas exiting the elements, there is a significant risk of liquid re-entrainment.
- ▶ Inlet and outlet port locations are critical. To avoid re-entrainment, the outlet port should be placed at a well-considered distance above the top of the elements unless a suitable baffle design is used to divert the gas flow up and around the baffle versus a sweeping motion across the side of the elements.
- ▶ As velocities are critical, the highest actual volumetric flow rate at operating conditions should be used for sizing to manage velocities and hydraulic drag forces. Therefore, vessels should be sized based on the largest flow and lowest pressure at actual operating conditions.
- ▶ Annular gas velocity and media face velocity are critical to performance, so both should be calculated to specify the number of elements, element spacing, and vessel inner diameter.
- ▶ The liquid loading capacity of both the elements and the vessel liquid accumulation chamber volume need to be understood and considered when sizing.
- ▶ The gas and liquid composition and temperature directly impact the choice of element material and construction. For example, surfactants in the liquid contaminant can impact droplet coalescence and necessitate the choice of an alternative media choice. Chemical and thermal incompatibility are leading causes of element failure, as seen in **Figure 12**.



Figure 12
Coalescer Element Failure

Finally, as mentioned previously, pre-filtration of gas streams for solids separation is highly recommended. As a note, the life of coalescer elements can be prolonged significantly by protecting them against plugging, thereby considerably reducing the recurring operational costs associated with element changeouts.

Test Methods and Efficiency Ratings of Gas-Liquid Coalescers

As coalescer technology evolves, it is important to measure accurately for performance, particularly in critical applications. In the filtration industry, there are a few trusted sources that provide standard testing practices.

- ▶ ANSI/CAGI ADF-400 Standard for Testing and Rating Coalescer Filters
- ▶ ISO 8573-2 Standard for Compressed Air – Contaminant measurement/oil aerosol content
- ▶ ISO 12500-3 Filters for Compressed Air – Test methods Particulates (for gas particle filters)

While many available separation products are tested to randomly modified procedures, it is always advisable to follow the standards prescribed by reputed industry sources like the ones listed above.

It is also important to understand the differences in removal efficiency reporting. There is considerable variation within the industry regarding performance reports, including:

- ▶ Reporting removal efficiency as a percentage at a specific droplet size, comparing outlet to inlet (e.g., 99.99% efficient at 1 micron size)
- ▶ Reporting efficiency as a percentage of contaminant concentration at the outlet relative to the inlet
Efficiency = $(c_{in} - c_{out}) / c_{in} \times 100$
- ▶ Reporting downstream concentration at specific test conditions (e.g., coalescer outlet of <10 ppbw while operating at 25°C, 1 atm, 40 ppm coalescer inlet concentration)

When evaluating the performance of different coalescers, the same reporting metrics should be used. Additionally, it is always advisable to be aware of the reporting measures, test conditions, and source of data, where possible.

Common Mistakes in Gas Separation Design, Specification, and Utilization

Corporate departmentalization is largely responsible for a continuous focus on CAPEX, with not enough emphasis placed on the OPEX impact of under-designed or improper process equipment. Project engineers are not necessarily at fault when working to meet specified goals or when trusting a vendor that claims its equipment can meet company design criteria.

Many times, operations personnel point out the inefficiencies of a piece of equipment and request budget approval for a replacement, only to find themselves with the same low-efficiency separator offered by a different vendor with one or two added features. Another common practice involves replacing equipment in-kind or copying equipment specifications from an existing plant and applying them to new facilities. While this can work if the plant design has been optimized and coalescer performance is meeting design criteria, often the same underperforming inlet gas separator placed at the original facility is duplicated at the company's other facilities.

Another common problem seen when troubleshooting inlet contamination issues involves finding a filter-separator as the “last line of defense” from liquid contamination on the inlet of a gas processing plant amine system. These “filter-separators” are mistakenly referred to as the plant’s inlet “coalescer.” Even though it removes liquids as low as 1 micron, it does not efficiently remove the critical submicron aerosols. The “filter-separator” is assumed to be a filter and a coalescer in one piece of equipment. However, its performance as a coalescer is often insufficient to protect the plant's operations, and the facility still requires a downstream high-efficiency coalescer vessel.

Yet another common problem involves well-designed vessels paired with inefficient elements. In this case, low-cost elements often mask critical inefficiencies that show up later in the form of costly issues downstream. In fact, when considering the cost impact of poor liquid contaminant removal on downstream processes, as outlined by Le Grange et al in Part 1 of this paper⁵, the cost of quality inlet gas coalescer elements are insignificant.

Inlet filters and coalescers are the most critical pieces of separation equipment in place to protect the gas processing plant. They are required for reliable acid gas stripping and outlet gas specifications to avoid flaring the valuable gas stream or foaming amine that ends up downstream.

If it is only required to change a set of coalescer elements once per year, wouldn't selecting the best elements that will provide reliable operations be the best approach? Too often, the focus is on the cost per element and not on using the most cost-effective technology for the operation. After all, inefficient operations, upsets, and downtime can easily pay for a set of high-efficiency elements in a period of minutes or hours.

A Case for High-efficiency Coalescers

Rumaih et al recently published a paper at the Laurence Reid Gas Conditioning Conference explaining the lessons they learned starting up a new gas processing facility in Saudi Arabia.²² The facility was designed to process 2.4 BSCFD of dry clean sour natural gas through an acid gas removal unit before going downstream to NGL recovery trains for further processing. However, due to operational challenges from contamination, they were only able to effectively process less than 1.6 BSCFD initially, with processing down to 1.1 BSCFD in 2017. Poor inlet filtration and separation were not the only operational issues, but they were significant contributors to the problems.

To ensure protection from contaminated inlet gas, the facility instituted regular pigging operations and particle filtration, as well as quarterly cleaning of their slug catchers to ensure entrapment of heavy solids and liquid contamination. To tackle the residual fine aerosols, they replaced their low-efficiency 1 micron-rated gas coalescers with high-efficiency 0.3 micron-rated coalescers. The high-efficiency coalescers provided reliable protection for their acid gas removal system. As a result of the tremendous impact the 0.3 micron gas coalescers made on their operations, Rumaih et al stated verbally at the LRGCC conference that Saudi Aramco changed its corporate gas coalescer specification to 0.3 micron for all of its gas processing facilities. The facility is currently processing 1.9 BSCFD.

Findings

This technical report has touched on the importance of liquid separation technology in the journey natural gas takes as it leaves the reservoir and moves through the process stream. As we have shown, the negative consequences of poor contaminant control are measurable for operators in terms of productivity, safety, and cost, and submicron aerosol droplets pose a significant challenge to gas processors and end users today. This report also discussed design considerations of a high-efficiency gas-liquid coalescer system for successful and reliable removal of these troublesome submicron aerosol contaminants, touched on common industry challenges related to gas separation design, specification, and utilization, and provided a recent example in which the installation of a properly designed, high-efficiency coalescer made a dramatic difference for a major operator.

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