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High Performance Liquid/Gas Coalescers for Compressor Protection

Presented at the 1999 Compressor Workshop, Lambton College, Sarnia, Ontario, April 28

by

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Abstract

Mechanical failures of reciprocating and centrifugal compressors can be caused in many instances by solid and liquid aerosol contamination in the intake gas. Protection of compressors by high efficiency liquid/gas coalescing filters has proven to be an effective means of reducing compressor maintenance and unscheduled shutdowns. A review of different liquid-gas separation devices is given with emphasis on high efficiency liquid-gas coalescers. On-site field test methods for determining aerosol contamination levels are presented along with a summary of extensive field results. Commercial experience with liquid-gas coalescers at different refinery and gas plant applications are discussed with operation experience and economic justification.

Introduction

Compressors are used for a number of applications within the refinery, chemical, gas processing, and gas transmission industries. While a number of different types of compressor designs exist, fundamentally they can be divided into positive displacement and centrifugal categories. Positive displacement involves the compression of gas by trapping the gas in isolated chambers that are then reduced in size before the gas is ejected. Reciprocating, screw and multi-lobe are examples of positive displacement compressors. In this paper, we will focus on reciprocating compressors due to their widespread use. Centrifugal compressors operate by accelerating the gas through the use of rotating blades and then restricting the exiting gas so that it is compressed in the process. These compressors can be of radial or axial design.

Contaminants in the inlet gas can have a severe effect on compressor reliability. A recent study[1] has found that at least 20% of all reciprocating compressor failures can be attributed to inlet gas contaminants. Even when the compressors are not having catastrophic failure, a costly maintenance schedule may be followed where the compressor is shut down every six months or less for inspection and minor repairs. A preventative system using a high performance liquid/gas coalescer system, however, has been found to provide protection of the compressor for a two-year period.

Gas contaminants are made up of solid particulates and liquid aerosols, often including a high percentage in the submicron size range. Solids are usually corrosion products (iron oxides or iron sulfides), salts or silt. Liquids can be hydrocarbons (refinery products, lube oil, condensate), aqueous (water, alcohol, dissolved salts, caustic, acid) or a combination of both. Contaminants will affect reciprocating and centrifugal compressors in different ways.

Reciprocating Compressor

Reciprocating compressors contain a cylinder and piston assembly with intake and exhaust valves similar to the familiar automobile engine. The gas enters the cylinder through intake valves, is compressed by the action of the piston confined in the cylinder, and then expelled through outlet valves. The motion of the piston is driven by a separate gas engine, turbine or electric motor. The valves play a crucial role in the compressor allowing the gas into the cylinder and for ejection of the gas after compression. The valves are especially prone to fouling from inlet gas contaminants. A build up of contaminants on the valves can lead to sticking valves or valves with partial bypass, resulting in a reduced compression ratio and increased power consumption. The build up of contaminants inside the cylinder can also damage the piston rings, pistons, and the cylinder wall. A survey[2] of 200 compressor users found that the cost of an unscheduled shutdown has been estimated for hydrogen gas service to range from $40,000 to $100,000 (US dollars) per day in lost production revenue not including repairs. The primary mode of failure was cited as the compressor valves followed by the pressure packings. The leading process improvements recommended by the compressor users was to install improved liquid/gas coalescing systems and gas filtration.

Centrifugal Compressor

Centrifugal compressors impart a dynamic head to the inlet gas by use of high speed impellers that are confined in a casing containing stationary diffusors. While centrifugal compressors are less sensitive to inlet gas contaminants, they are still adversely affected. For centrifugal compressors, the primary contaminant related problem is the build up of foulants on the rotating blades (also known as salting). This can lead to a partial blockage in the flow path causing increased power consumption and can create an imbalance in the blades leading to serious mechanical failures due to resultant vibrations if left unchecked. Usually, the centrifugal compressors are taken off-line for cleaning at regular intervals and this represents a substantial cost for maintenance.

Liquid/Gas Separation Options

Currently there are a number of liquid-gas separation technologies and a brief review of some of these options is presented. An important design feature in liquid/gas separators, the turn down ratio, is also discussed for the different separation equipment. The turn down ratio is the ratio of the design flow rate to the operating flow rate at which good separation is still achieved. A high turn down ratio indicates that the separation equipment will operate effectively even at reduced flow rates.

Knock Out Separator

Also known as the gravity settler, the knock out pot or drum is a vessel that allows the gas to expand and as a result, the gas velocity is reduced. Gravitational forces cause the larger droplets (usually > 300 μm) to separate from the gas stream. Generally, these systems require a large vessel and are used primarily for bulk removal and slugs. As the flow rate is decreased or the vessel diameter design is increased, a higher efficiency will result and so the turn down ratio is high for these separation systems. Also, waxy or fouling material will not cause plugging and these systems operate with a low differential pressure. The knock out or gravity settler is not recommended as the only separation equipment, as fine mist will not be removed. These systems do play an important role in a multistage system of aerosol removal as the front line separation device.

Centrifugal Separator

Also known as cyclone separators, the rotating action of the gas creates centrifugal forces much higher than the gravitational forces in the knock out drums, allowing for a greater efficiency of separation. Generally, the centrifugal separators can remove liquid aerosols greater than 10 μm with high efficiency, but will allow the finer aerosols to pass. As the gas flow rate is lowered, the centrifugal force will be reduced and, as a consequence, the aerosol removal efficiency will also be diminished. This gives the centrifugal separator a poor turn down ratio. Similar to the knock out separators, waxy or fouling material will not cause plugging and these systems operate with a low differential pressure.

Vane Separator

Vane separators consist of metal baffles or plates within a vessel that present a tortuous path for the gas flow so that aerosol droplets impinge on the metal surfaces. Once the drops contact the metal surfaces they pool together and are drained by gravity. The principal separation mechanism for vane separators is inertial impaction. In this case, the aerosol droplets will deviate from the gas streamlines and impact onto the vanes. As the flow rate is lowered, the driving force for separation is lessened, resulting in a poor turn down ratio and decreased separation efficiency at low flow rates. Vane separators can offer good separation for aerosol drops greater than 10 μm and are able to handle high liquid inlet concentrations.

Mesh Pad

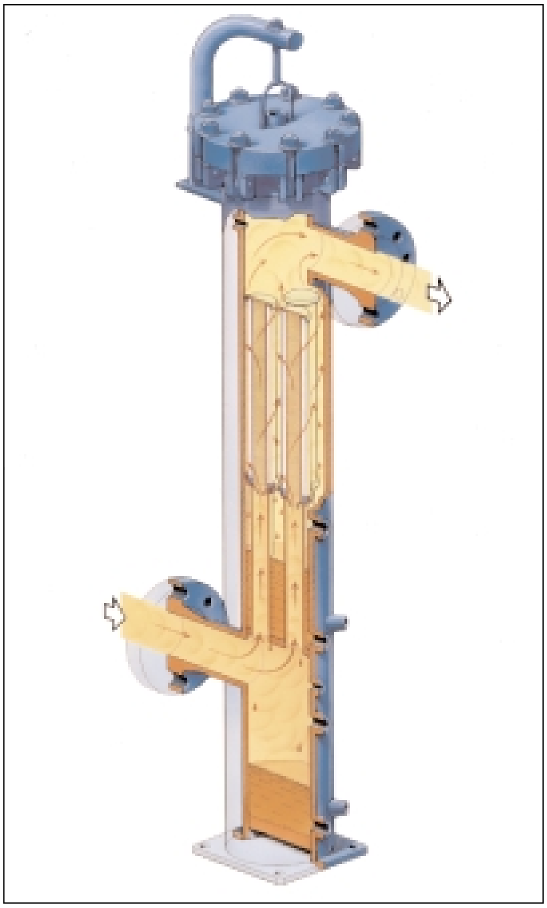
A mesh pad, or mist eliminator consists of a pad that is composed of fibers or knitted mesh that is usually placed at the top of a vertical vessel. As the gas passes through the pad, aerosol drops are intercepted by the fibers and coalesce into larger drops until the pad is saturated with liquids that drain from the pad to the bottom of the vessel by gravity. The mesh pads provide more surface area for drops to collide as compared to the vane separator, but still operate on the same primary separation mechanism of inertial impaction. For inertial impaction, the separation efficiency is decreased by lowering the flow, and the turn down ratio is poor. Mesh pads generally have good removal ratings for droplets greater than 10 μm and can be designed to process high inlet liquid loadings.

Liquid/Gas Coalescers

The coalescer cartridge is usually made from glass fiber media that is supported by a metal core and contains a much finer pore size and larger surface area as compared to mesh pads or vane separators. The fine pore size allows for a different mechanism of separation for the coalescers. The coalescers are able to intercept the aerosol droplets by direct interception (sieving) as well as by the method of diffusional interception. Separation by the diffusion mechanism is caused by the random (Brownian) motion of the fine aerosol droplets that increase the probability of collision with coalescer fibers. The diffusional interception and direct interception differ from inertial impaction in that as the gas flow rate is decreased, the removal efficiency increases and, therefore, provides for a high turn down ratio. Properly designed high efficiency liquid-gas coalescers can provide separation of aerosols as low as 0.1 μm.

High efficiency liquid/gas coalescers are generally constructed from glass fibers since this material allows for a fine porous structure with fiber diameters of a few microns. The small pore size is needed to achieve greater capture and separation of these fine aerosols. The separation of liquid aerosol contamination with high performance liquid/gas coalescer cartridge systems has found widespread acceptance in refinery and gas plants in recent years for a number of applications[3,4,5] including protection of compressors, turbo equipment, burner nozzles, amine and glycol contactors, molecular sieve beds, and hydrotreater catalyst beds. This has largely been the result of traditional separation approaches including knock out vessels, centrifugal separators, mesh pads or vane separators not meeting the end user's requirements for aerosol reduction. The primary rationale for the use of high efficiency coalescers is that significant aerosol contaminant exist in the plants that are in the sub micron and low micron size range[6].

Figure 1
Pall Vertical High Efficiency Liquid/Gas Coalescer System



Another significant benefit of the liquid/gas coalescer is that this type of separation device can be operated at significantly lower flow rates than the initial design flow rate which means it has a high turn down ratio. This is due to the fact that the separation mechanisms are based primarily on diffusion and direct interception unlike vane separators and mesh pads that rely heavily on inertial separation principles. This allows the high efficiency liquid/gas coalescer systems a greater degree of flexibility and they can operate at peak performance even for high turn down ratios (reduced flow rates) which can occur during commonly encountered partial plant shutdowns and upset conditions. Generally, the high efficiency liquid/gas coalescers are used for inlet aerosol concentrations of less than 1,000 ppmw (0.1%) and are placed downstream of other bulk removal separators as the final stage. Outlet concentrations for these high efficiency liquid/gas coalescers are as low as 0.003 ppmw[6,7,8].

The use of a surface treatment[9] on high performance vertical liquid/gas coalescer cartridge systems has been proven to significantly enhance performance by allowing higher flow rates or smaller housing diameters compared to untreated coalescers.

A Pall vertical high efficiency liquid/gas coalescer system is depicted in Figure 1. The inlet gas with liquid aerosol contamination first enters at the bottom of the housing into a first stage knock out section. Here any slugs or larger size droplets (approximately > 300 µm) are removed by gravitational settling. The gas then travels upward through a tube sheet and flows radially from the inside of the cartridges through the coalescer medium to the annulus. The inlet aerosol distribution is in the size range of 0.1 µm - 300 µm and after passing through the coalescer medium is transformed to enlarged coalesced droplets in the size range of 0.5 - 2.2 mm. The advantage of flowing from the inside to outside of the coalescer cartridge is that the gas velocity can be more easily adjusted in the annulus by selecting the optimum housing diameter to prevent re-entrainment of coalesced droplets.

As the gas leaves the coalescer cartridge and travels upward in the annulus it contributes to the total flow, thereby increasing the annular velocity. The annular velocity is modeled as a linear function with vertical distance, and the annular velocity is zero at the bottom of the cartridge and increases to a maximum value at the top of the cartridge.

Figure 2a and 2b
Effect of Surface Treatment on Annular Velocity

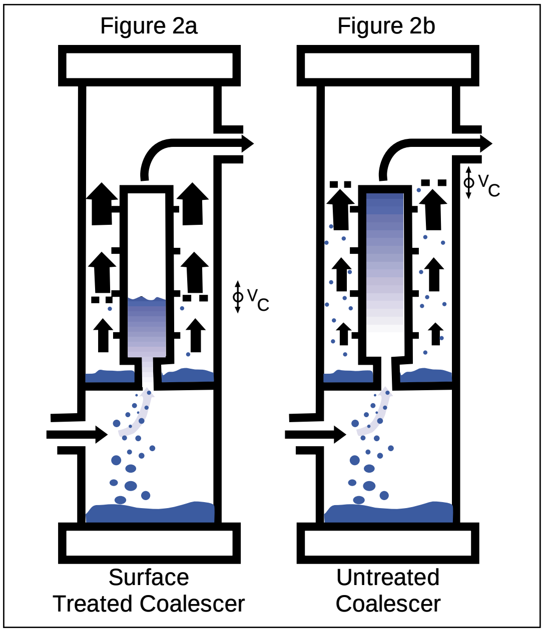


Figure 2a

Figure 2b

Surface Treated Coalescer

Untreated Coalescer

Once the coalesced droplets are formed, they immediately drain vertically downward in the coalescer medium pack. The surface treatment greatly enhances this drainage and, as a direct consequence of the treatment, the coalesced droplets are shielded from the upward gas flow in the annulus in most of the length of the coalescer cartridge. The coalesced droplets are first exposed to the annular gas flow when they appear on the external face of the coalescer medium pack at the bottom third of the coalescer cartridge (See Figure 2a). Once the coalesced droplets are released to the annular space they are subject to the force of the upward flowing gas. The trajectory of the coalesced droplets is modeled on a force balance between gravity settling and the drag force created by the gas flow past the droplets. This analysis leads to the calculation of a critical annular velocity for re-entrainment.

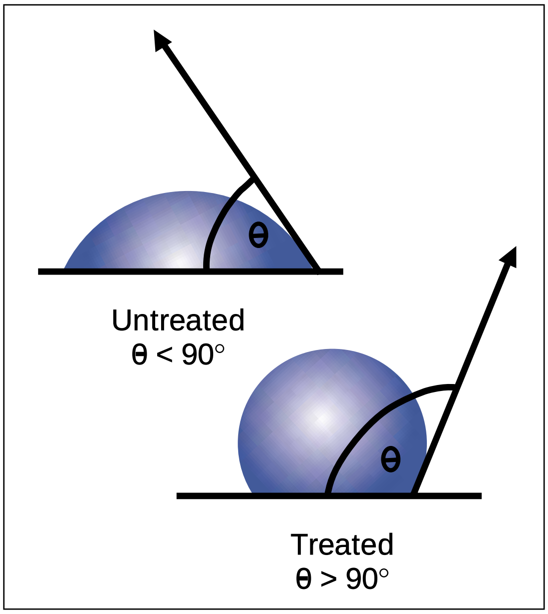
Due to the surface treatment, there are minimal coalesced droplets present in the annulus above the drainage point at the bottom third of the coalescer cartridge. For a coalescer cartridge that is not specially surface treated, the coalesced liquids are present throughout the length of the coalescer in the annulus space and the critical annular velocity for re-entrainment is given for the top of the element (See Figure 2b). For the treated coalescer, it is allowable to have annular velocities greater than the critical value for re-entrainment in the portion of the annulus space where there are no liquids present. This allows the maximum annular velocity at the top of the coalescer cartridge to be about three times the critical re-entrainment value needed at the vertical position of the lower one-third of the cartridge height where liquids are present.

Therefore, the maximum annular velocity at the top of the coalescer cartridge is found to be about three times greater than the value for an untreated coalescer. The annulus area is determined using the maximum allowable annular velocity and designed to be of sufficient size to prevent re-entrainment and as small as possible to minimize the housing diameter.

The liquid/gas coalescer is constructed of an inner rigid stainless steel core around which is placed the active pleated glass fiber coalescer medium. The pore structure in the coalescer medium is tapered by using layers of increasing pore size. The inlet gas first encounters the smallest pores that increase with penetration distance to allow for more space as the coalesced droplets grow. The pleated coalescer medium is supported by a mesh structure to provide mechanical strength which is then followed by a coarse outer wrap which serves as a drainage zone. The entire coalescer cartridge is treated with an aqueous fluorocarbon emulsion which penetrates through the depth of the glass fiber coalescer medium and drainage layers leaving a thin fluorocarbon coating on all of the surfaces. The result is that the surface energy of the coalescer medium is lowered sufficiently to prevent most liquids from wetting out the coalescer fibers.

This treatment effectively creates a coalescer medium which is both hydrophobic (water repellent) and oleophobic (oil repellent). This effect can be characterized through use of contact angle measurements. In Figure 3, a droplet is placed on a surface treated glass fiber and an untreated glass fiber. The degree at which the droplet is spread out or wetted is measured by the contact angle of the liquid with the solid. For drops which are not strongly adsorbed to the solid surface, the contact angle is greater than 90 degrees while the untreated wetted surface has a contact angle approaching zero degrees. Another way to demonstrate this effect is to dip a section of the coalescer medium into a test liquid and compare to an untreated coalescer section. The treated coalescer medium quickly sheds the liquid, while the untreated coalescer medium absorbs the liquid and acts as a sponge.

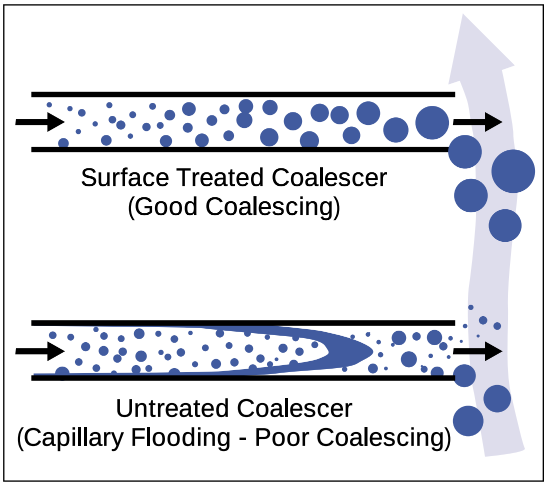
Figure 3
Contact Angle of Treated and Untreated Coalescer Medium



The degree that the liquid aerosols wet out the coalescer fibers has remarkable effects on coalescer performance. One such effect is capillary flooding which is illustrated in Figure 4. Liquid aerosols entering an idealized cylindrical pore made from untreated coalescer medium result in the liquids forming a continuous layer along the walls of the capillary. As more liquids enter the pore, the liquids coating the pore walls build up and eventually block the pore completely. The gas pressure then rises in the pore and ultimately causes the drop to be ejected from the pore in such a manner that the drop is atomized into a number of smaller droplets. These droplets are smaller than the largest drop size possible by coalescence, and are re-entrained by the annular flow. A surface treated coalescer pore behaves quite differently, and the liquids do not wet the capillary walls due to the weak interaction between the liquid aerosols and the surface treated pore walls. The drops instead tend to coalesce with each other throughout the length of the pore, and when they leave the coalescer medium are at the largest possible size by coalescence. The large drops then settle by gravity and are not re-entrained. Notice in the case of the treated coalescer pore that the walls of the pore do not become wetted out, and that the capillary cross section is never blocked so that atomization does not occur.

Another effect of the surface treatment is that it provides the coalescer with anti-fouling abilities. Most of the solids in the gas are associated with the liquid aerosol droplets. The ability of the surface treated coalescer to repel these droplets and not wet out also prevents solid contaminants from adhering to the coalescer fibers. This allows the coalescer to provide an extended service life over non-treated coalescers. Typical field service life encountered for the surface treated coalescer is from 1 - 2 years while traditional coalescers have been found in specific cases to last from 2 - 6 months.

Figure 4
Effect of Surface Treatment on Media Velocity



The surface treatment also allows the coalescer to operate with less hold up volume of liquids as they tend to drain quickly due to the low attraction between the coalescer fibers and the liquid drops forming. The result is that a less obstructed pathway is created for the gas passing through the coalescer and, consequently, a lower overall pressure drop is experienced as compared to untreated coalescers.

The primary effect of the surface treatment is to enhance drainage of the coalesced liquids. This results in improved capability to handle higher inlet liquid concentrations, higher annular velocities and lower pressure drop.

Modeling the Liquid/Gas Coalescer

The modeling of the liquid/gas coalescer system can be divided into two basic aspects for performance: media velocity and annular velocity. The other consideration to be taken into account is pressure drop. The pressure drop for a given system can be decreased by using more coalescer elements.

Media Velocity

The media velocity (v_{med}) is defined as the actual flow rate divided by the coalescer filter area:

$$V_{med} = Q_a / NA_{med} \tag{1}$$

where: Q_a = actual system flow rate (at system conditions)
N = number of coalescers
A_{med} = media area for one coalescer

and Q_a is obtained from the standard system flow rate (Q_s):

$$Q_a = Q_s Sg \rho_{air,stp} / \rho_g \tag{2}$$

where: Sg = gas specific gravity
$\rho_{air,stp}$ = density of air at standard temperature and pressure
ρ_g = density of gas at system conditions

The media velocity is not the actual velocity through the open pores of the media, but rather an average by convention over the combined pore area and solid matrix area in the spatial plane normal to the flow direction. The maximum media velocity for a coalescer construction is related to a number of factors intrinsic to the particular coalescer design and to the physical properties of the system. Four steps have been identified with the mechanism of the formation and removal of droplets in the coalescer medium:

1) capture	3) release
2) coalescing	4) drainage

The formation of the coalesced droplets first involves the capture of the small aerosols onto the fibers of the coalescer medium. The actual coalescing or merging of the fine droplets is believed to take place on the fibers and especially at fiber intersections. The coalesced droplets are then released from the fiber due to the drag force of the gas flow exceeding the adsorption energy. This process is repeated through the depth of the coalescer medium until the coalescing process is completed and the largest possible stable droplet size is achieved. During the coalescing stages, the growing droplets are also draining downward inside the media pack due to the force of gravity.

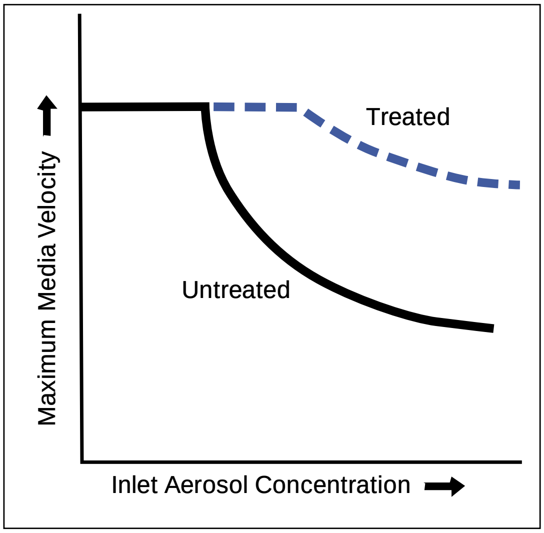
The surface treatment allows the release and drainage process to proceed at a faster rate which, in turn, frees up more coalescing sites on the fibers and allows the coalescer to process higher inlet liquid aerosol concentrations than the untreated coalescer medium.

Effect of System Conditions on Media Velocity

The ability of the coalescer medium to perform effectively will also depend on the system environment. While different coalescer constructions will exhibit quantitative differences, they will follow the same qualitative behavior. The media velocity has been determined to depend on system parameters such as inlet aerosol concentration, aerosol density, gas density, and gas viscosity. An analysis of how the inlet liquid aerosol concentration affects the maximum media velocity is presented in Figure 5 for surface treated and untreated coalescer media.

At low aerosol concentrations, the maximum media velocity is constant and is unaffected by aerosol levels. Under these conditions the media is limited by the capture mechanism and is not affected by drainage. At higher levels of aerosol concentration, the coalescer medium becomes limited by drainage and is inversely proportional to the aerosol concentration. The effect of the surface treatment on this process is to enhance the drainage and allow for higher maximum media velocities under the same aerosol loading when limited by drainage. The plot of the surface treated coalescer media is based on an increase in drainage ability of about threefold. The effect of the increased drainage of the surface treatment is to extend the constant portion of the plot and raise the drainage limited curve to three times the untreated value.

Figure 5
Effect of Surface Treatment and Liquid Loading on Media Velocity



Annular Velocity

The annular velocity (v_{ann}) is defined as the actual flow rate divided by the annulus area:

$$v_{ann} = Q_a/A_{ann} \qquad (3)$$

where: A_{ann} = cross sectional annular area defined as the cross sectional area of the housing without coalescers minus the area of the coalescer end caps:

$$A_{ann} = \pi R_h^2 - N\pi R_c^2 \qquad (4)$$

where: π = numerical constant (3.14....)
R_h = radius of the housing
R_c = radius of coalescer end cap
N = number of coalescers

The enlarged droplets leaving the coalescer media pack can be assumed to be as large as possible for the given flow conditions when complete coalescence has occurred. Therefore, the coalesced droplet diameter will be the same for any specific design of the coalescer cartridge as long as complete coalescence has been achieved. If complete coalescence is not achieved, the calculation of the coalesced droplets must take into account the degree of coalescence.

In most industrial applications, the coalesced droplets will range in size from 0.5 - 2.2 mm and will be mostly influenced by the interfacial tension which is significantly affected by the liquid density, system temperature, and system pressure. As the pressure is increased, the gas density will increase while the liquid density is only slightly affected. The solubility of the gas in the liquid is enhanced with increasing pressure. This leads to a substantial decrease in interfacial tension with increasing pressure and, consequently, to significantly smaller coalesced droplets at the higher pressures.

Once the coalesced droplet size has been estimated, the next step is to determine the maximum annular velocity that can be sustained without re-entrainment. In general, the coalesced droplets will produce Reynolds numbers (Re) outside of the creeping flow regime (< 0.1) and Stokes law. Instead, a force balance is used between the liquid droplets settling by gravity and the drag force of the gas flowing upwards in the opposite direction.

Determination of Minimum Housing Diameter

The housing diameter is determined from the area of the annulus and the area of the coalescer end caps. The maximum annular velocity at the top of the coalescer cartridges is used to determine the annular area required. The value of the maximum annular velocity [v_{ann} (max)] at the top of the coalescer cartridges is dependent on the critical annular velocity for re-entrainment (v_c) and the vertical location at which the coalesced droplets are present in the free annulus space. This relationship can be described as follows:

$$v_{ann}\,(\mathrm{max}) = k_a v_c \qquad (5)$$

where: k_a = annular velocity enhancement factor due to drainage

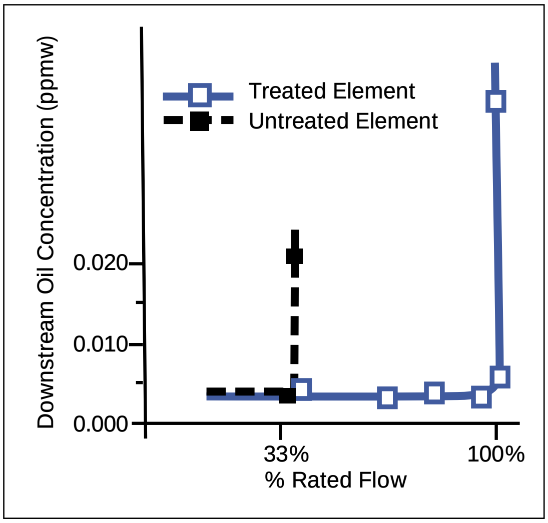


Figure 6
Laboratory Results for Treated and Untreated Liquid/Gas Coalescer Performance

For the untreated coalescer medium the coalescer cartridge is completely wetted and coalesced droplets are present in the annulus space up to the top of the annulus where the annular velocity is highest. There is no drainage enhancement and $k_a = 1$. The maximum annular velocity to prevent re-entrainment is then equal to the critical value for re-entrainment:

Untreated Coalescer:

$$v_{ann}\,(\mathrm{max}) = v_c \qquad (6)$$

The effect of the surface treatment is to greatly increase the drainage and the annular velocity at the top of the coalescer cartridge can now be significantly higher than the critical value since there are no coalesced droplets present in the annulus except in the bottom third of the cartridge. The maximum annular velocity is now determined with $k_a = 3.1$ as follows:

Surface Treated Coalescer:

$$v_{ann}\,(\mathrm{max}) = 3.1 v_c \qquad (7)$$

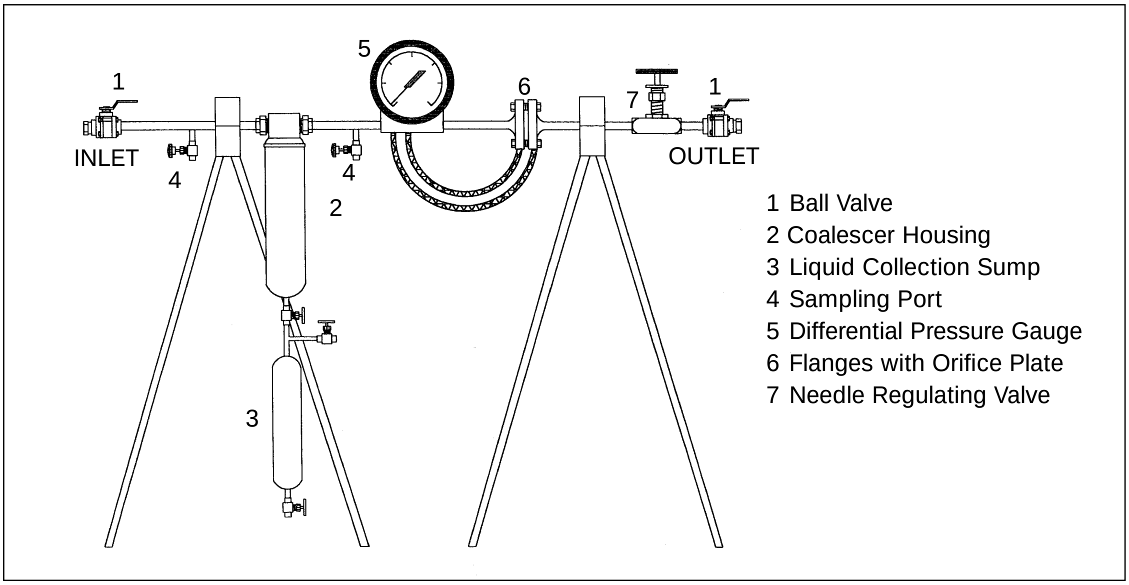
Convincing evidence for the enhanced maximum annular velocity given by equation (5) has been demonstrated by laboratory tests[6,7,8] and is presented in Figure 6. Visual observations during these tests also confirm that liquids are present on the outside of the coalescer pack only at the bottom third for the surface treated coalescer and are present throughout the length of the wetted untreated coalescer.

Pilot Scale Liquid/Gas Coalescer Tests

A pilot scale Pall high performance liquid/gas coalescer was used to sample a sidestream of gas to determine the liquid aerosol concentration.

A schematic of the coalescer test stand is presented in Figure 7. The test apparatus consisted of a Pall Coalescer test housing that held a five inch length test coalescer. The test stand was equipped with needle valves and an orifice meter to control the gas flow rate.

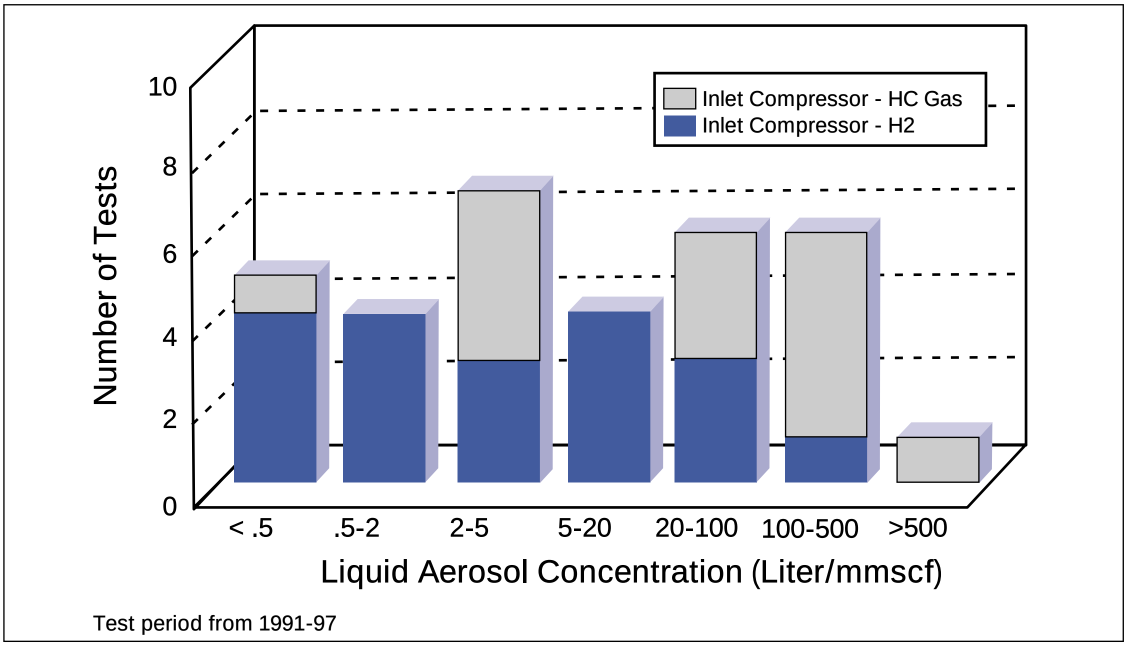
Figure 7
Pall Pilot Scale Liquid/Gas Coalescer Test Equipment



The test equipment had been pressure tested up to 1,500 psig and contained 1″ stainless steel tubing and NPT end connections. A computer sizing program was used to correlate the differential pressure across the orifice plate to the gas flow rate. A small gas sidestream (approximately 4 acfm) was flowed through the test coalescers for the test period (1/2 - 2 days). The concentration of liquid aerosol removed from the inlet gas was then calculated from the amount of gas flowed through the test stand and the volume of liquid collected.

The solid aerosol content in the gas was determined by an in-line field test method whereby gas solids were collected on analysis membranes at system conditions. Test apparatus consisted of a 47 mm test jig, metering valves, pressure gauge, and a spring loaded flow meter to control the gas flow. The test jig was loaded with a preweighed analysis membrane rated at 0.01 µm in gas service. The gas was flowed through the test jig at approximately 1 acfm for 4-8 hours to trap gas contaminants. The sampled gas analysis membranes were then placed in a filtration funnel and rinsed with 0.2 µm filtered solvents by the application of vacuum to remove any oil or liquid contaminants. The rinsed membranes were then dried in an oven at 80°C, desiccated and brought to constant weight. The total suspend-

Figure 8
Pall Sidestream L/G Coalescer Field Test Results at Inlet to Compressor

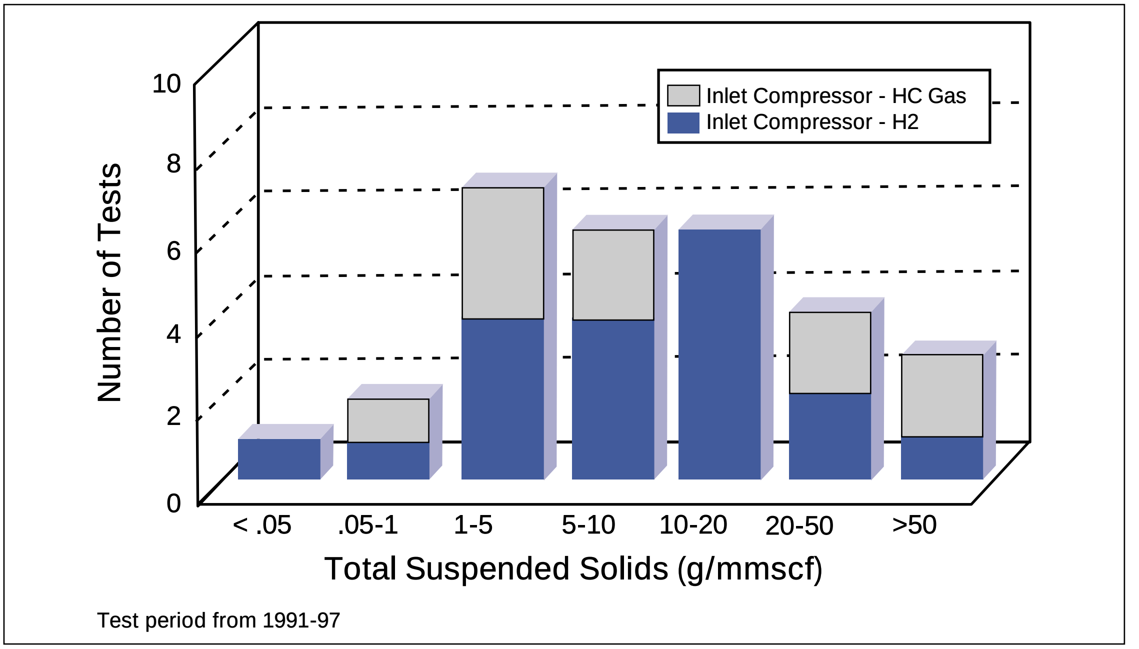


Test period from 1991-97

ed solids were determined from the membrane weight difference and the total amount of gas flowed through the test jig.

Field data collected at the inlet to compressors from gas processing plants, gas transmission stations, and refineries are presented in Figures 8-9. The data shows that high levels of solids and liquids are challenging compressors in actual service. The liquids were found to range from < 0.5 liter/mmscf to > 500 liter/mmscfd with most of the tests in the range of 2 – 500 liter/mmscfd. The solids were found to vary from < .05 g/mmscf to > 50 g/mmscf with most of the tests indicating solids in the range of 1 to 50 g/mmscf. These tests were conducted downstream of multiple separation devices including knock out pots, filter-vane separators and mesh pads. The field tests for the liquid content were run over extended periods up to two days, and this was found to be crucial in obtaining representative data as fluctuations in the gas contaminant levels are commonplace in gas streams.

Figure 9
Pall Solid Concentration Field Test Results at Inlet to Compressor



Test period from 1991-97

Commercial Equipment

Application of the high efficiency liquid/gas coalescer to three different applications are presented below:

Case 1:
North Sea Offshore Platform

An Offshore Platform in the North Sea has been operated by an alliance team that processes approximately 363,000 kg/hr of Natural Gas at 45.5 bar absolute and 32°C. The platform has successfully operated for a number of years supplying gas to the UK using a centrifugal compressor.

Problem

Costly maintenance to the compressor system was a major drawback and the alliance decided that improved liquid/gas separation was required to alleviate this situation. The platform compressor was being challenged with natural gas that contained a high concentration of produced water from the wells. This water was saturated with salt that ultimately crystallized in the compressor causing it to trip-out. Each incident required costly cleaning, rebuilding and, most importantly, off-line time for the platform and the onshore processing plant in the UK. Approximately 0.5 tons of salt were deposited in the centrifugal compressor casing over an operating period of about six months.

The actual cost for this non-conformance, before installation of the Pall SepraSol™ high performance liquid/gas coalescer, is estimated to be upwards of $1,000,000/year, taking into account unscheduled repairs, lost sales gas production and the prospect of penalty payments as a direct result of the lost production.

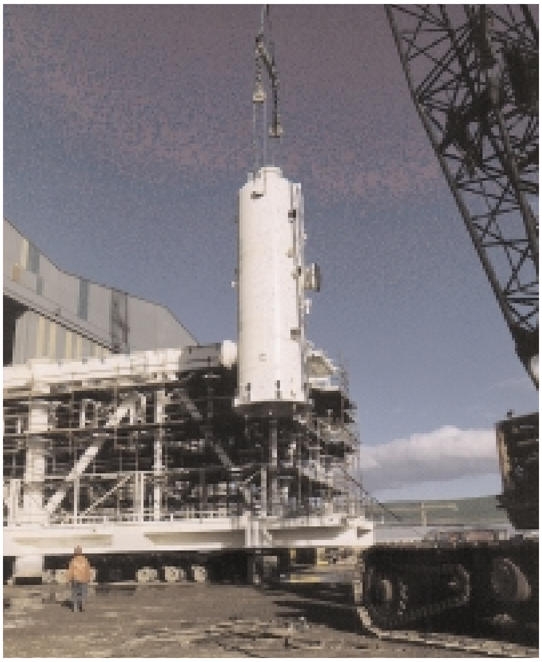


Figure 10
Liquid/Gas
Coalescer Unit

Solution

A Pall SepraSol high performance liquid/gas coalescer system was designed to reduce the inlet free liquid concentration of 1860 ppmw of produced water down to 0.003 ppmw in the effluent. A three stage system was used to achieve this separation performance goal while reducing the footprint and overall weight of the system. The separation system consisted of a single vertical vessel of approximately 2 meters diameter, with an overall height of 9.3 meters. A special mesh pad and 130 coalescing cartridges were used in the internals. The design code was BS5500, category 1 with 24 inch inlet and outlet nozzles.The final operational weight for the complete system was 77 tons. A photograph of the assembled liquid/gas coalescer unit prior to installation on the platform is provided in Figure 10.

As the gas first enters the vessel, free liquids with a diameter > 300 microns are separated in the lower sump by gravity. The second stage consists of a specially configured mesh pad to remove liquid droplets greater than about 10 micron. The liquids knocked out by gravity and the mesh pad are pooled together into the lower sump. The final gas treatment stage occurs in the upper section that contains the Pall SepraSol high performance liquid/gas coalescing cartridges. Here, the fine mist or sustainable aerosols in the range of 0.1 microns and larger are coalesced into large drops in the millimeter range that are subsequently separated by gravity into an upper sump. Both upper and lower sump are drained automatically using a level sensor and automated valves.

Since installation, the Pall liquid/gas coalescing system has worked flawlessly and has met the alliance's expectations. There have been no further instances of compressor trip-out or need for unscheduled maintenance, and the salt deposition problem has been completely eliminated, with complete user satisfaction.

Case 2:

USA Midwest Natural Gas Transmission

Process

A natural gas compressor station located in the USA Midwest contains two trains that process an estimated 14 mmscfd of gas. The compressors are of a reciprocating design and the natural gas is being fed to a triethylene glycol (TEG) dehydration plant to remove water vapor prior to sales distribution.

Problem

Solid and liquid aerosol contamination were passing through existing liquid/gas coalescers leading to fouling of the compressor valves and a resultant unscheduled shutdown for repairs. The cost to rebuild the compressor including downtime, labor, parts, and loss of production was in excess of $250,000. The existing coalescers were also being fouled requiring changeout every 6 - 8 weeks.

Solution

Pall SepraSol high performance liquid/gas coalescers were installed upstream of the compressor in the existing vessel that was 24 inches in diameter and held 19 coalescers. The high efficiency coalescers had a patented surface treatment that renders them oleophobic (oil repellent) and hydrophobic (water repellent). The result was that the new coalescers were able to effectively reduce the liquid and solid aerosol contaminant down to undetectable limits and also achieve a service life of 12-13 months. Since the installation of the high efficiency coalescers, the compressor has not had any unscheduled shutdowns and the gas transmission company decided to install Pall SepraSol liquid/gas coalescers in its other coalescing units.

Case 3:

Canadian Refinery: Recycle Hydrogen

Process

A reciprocating compressor is used in a recycle hydrogen gas stream at a Canadian refinery. The hydrogen is a feed to a high pressure hydrocracker with a flow rate of 57.5 mmscfd, a pressure of 1,800 psi and a temperature of 120°F. The gas originates from a platforming unit which also has a knockout pot containing a mesh pad liquid/gas separator.

Problem

Excessive liquid aerosols were being carried over from the platformer unit in the form of a fine hydrocarbon aerosol that was passing through the mesh pad/knockout separator. On occasion, upsets could also lead to the presence of ammonia chlorides in the aerosol stream as organic chlorides are injected into the platformer to enhance catalytic activity.

The reciprocating compressor on the hydrogen recycle stream was experiencing maintenance problems due to valve and cylinder fouling. This caused unscheduled shutdowns every 2-3 months. The fouling material was determined to be polymerized hydrocarbon sludge. Compressor repairs cost $375,000 annually and additional margin losses of $22,000 for each day of shutdown.

Solution

A Pall SepraSol high efficiency liquid/gas coalescer was installed upstream of the recycle compressor. This unit was constructed of carbon steel for a design pressure rating of 2,050 psig to ASME Code Section VIII, Div. 1, with a 12 inch diameter and 4 inch, 1500# RFWN flanges. The unit contained a lower knockout sump for any liquid slugs and an upper sump containing four high efficiency liquid/gas coalescers to separate the fine aerosol mist.The relatively small size of this coalescer installation represented a modest investment for the refinery. After the coalescer unit was installed the unscheduled compressor shutdowns were eliminated. The coalescer elements lasted an average of 8 - 12 months.

Conclusions

High performance liquid/gas coalescers can play a vital role in compressor protection. Some of the key points covered in this paper included:

1) A high level of compressor problems are caused by solid and liquid aerosol contaminants in the inlet gas.
2) Proper protection of the compressor with high efficiency liquid/gas coalescers can extend the service life between maintenance to two years.
3) Field test results at the inlet to compressor systems indicate that high levels of aerosol liquids and solids are passing through widely used separation equipment.
4) Improved separation can be achieved by high performance liquid/gas coalescers.
5) All coalescer systems are not the same - surface treatment has been found to substantially increase the separation capability of liquid/gas coalescers and extend their service life.
6) Commercial experience at three sites provided economic justification of using high performance liquid/gas coalescers.

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