Pall Corporation

Scientific & Technical Report GAS-4310b

Recent Developments In Liquid/Gas Separation Technology

Filtration. Separation. Solution. SM

Scientific & Technical Report

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Introduction

Removing liquids and solids from a gas stream is very important in refining and gas processing applications. Effective removal of these contaminants can prevent costly problems and downtime with downstream equipment like compressors, turbines, and burners. In addition, hydrocarbons and solid contaminants can induce foaming in an amine contactor tower[1] and can contribute to premature catalyst changeouts in catalytic processes. In compressors that use oil to lubricate cylinders, the lube oil often gets into the discharge gas causing contamination downstream. A thin film of hydrocarbon deposited on heat exchangers will thicken and coke, decreasing heat transfer efficiency, increasing energy consumption and creating a risk of hot spots and leaks.

Several technologies are available to remove liquids and solids from gases. This paper will first provide selection criteria for the following gas/liquid separation technologies:

- gravity separators
- centrifugal separators
- filter vane separators
- mist eliminator pads
- liquid/gas coalescers

and then focus on the separation of fine aerosols from gases using liquid/gas coalescing technology.

Removal Mechanisms

Before evaluating specific technologies, it is important to understand the mechanisms used to remove liquids and solids from gases. These can be divided into four different categories.[2] The first and easiest to understand is gravity settling, which occurs when the weight of the droplets or particles (ie. the gravitation force) exceeds drag created by the flowing gas.

A related and more efficient mechanism is centrifugal separation which occurs when the centrifugal force exceeds the drag created by the flowing gas. The centrifugal force can be several times greater than gravitational force.

The third separation mechanism is called inertial impaction which occurs when a gas passes through a network, such as fibers and impingement barriers. In this case, the gas stream follows a tortuous path around these obstacles while the solid or liquid droplets tend to go in straighter paths, impacting these obstacles. Once this occurs, the droplet or particle loses velocity and/or coalesces, and eventually falls to the bottom of the vessel or remains trapped in the fiber medium.

And finally, a fourth mechanism of separation occurs with very small aerosols (less than 0.1 µm). Called diffusional interception or Brownian Motion, this mechanism occurs when small aerosols collide with gas molecules. These collisions cause the aerosols to deviate from the fluid flow path around barriers increasing the likelihood of the aerosols striking a fiber surface and being removed.[3]

Throughout this paper, reference to droplet and particle sizes will be in the unit micron. One micron is 1/1000 of a millimeter or 39/1,000,000 of an inch. Figure 1 shows the size of various material in microns.

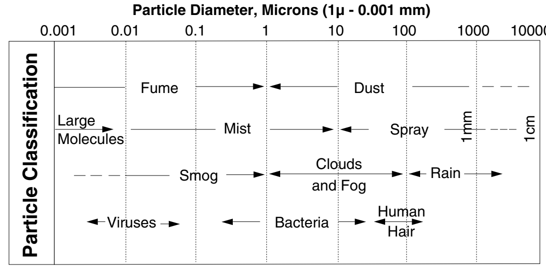


Figure 1: Particle Diameters of Typical Contaminants

Gravity Separators

In a gravity separator or knock-out drum, gravitational forces control separation. The lower the gas velocity and the larger the vessel size, the more efficient the liquid/gas separation. Because of the large vessel size required to achieve settling, gravity separators are rarely designed to remove droplets smaller than 300 microns.[4] A knock-out drum is typically used for bulk separation or as a first stage scrubber. A knock-out drum is also useful when vessel internals are required to be kept to a minimum as in a relief system or in fouling service.[5] Gravity separators are not recommended as the soul source of removal if high separation efficiency is required.

Centrifugal Separators

In centrifugal or cyclone separators, centrifugal forces can act on an aerosol at a force several times greater than gravity. Generally, cyclonic separators are used for removing aerosols greater than 100 µm in diameter and a properly sized cyclone can have a reasonable removal efficiency of aerosols as low as 10 µm. A cyclone's removal efficiency is very low on mist particles smaller than 10µm.[6] Both cyclones and knock-out drums are recommended for waxy or coking materials.

Mist Eliminators

The separation mechanism for mist eliminator pads is inertial impaction. Typically, mist eliminator pads, consisting of fibers or knitted meshes, can remove droplets down to 1-5 microns but the vessel containing them is relatively large because they must be operated at low velocities to prevent liquid reentrainment.

Filter Vane Separators

Vane separators are simply a series of baffles or plates within a vessel. The mechanism controlling separation again is inertial impaction. Vane separators are sensitive to mass velocity for removal efficiency, but generally can operate at higher velocities than mist eliminators, mainly because a more effective liquid drainage reduces liquid reentrainment. However, because of the relatively large paths between the plates constituting the tortuous network, vane separator can only remove relatively large droplet sizes (10 microns and above). Often, vane separators are used to retrofit mist eliminator pad vessels when gas velocity exceeds design velocity.[7]

Liquid/Gas Coalescers

Liquid/gas coalescer cartridges combine features of both mist eliminator pads and vane separators, but are usually not specified for removing bulk liquids. In bulk liquid systems, a high efficiency coalescer is generally placed downstream of a knock-out drum or impingement separator. Gas flows through a very fine pack of bound fibrous material with a wrap on the outer surface to promote liquid drainage (See Figure 2 below). A coalescer cartridge can trap droplets down to 0.1 micron. When properly designed and sized, drainage of the coalesced droplets from the fibrous pack allows gas velocities much higher than in the case of mist eliminator pads and vane separators with no liquid reentrainment or increase in pressure drop across the assembly.

Figure 2: Coalescer Cutaway View

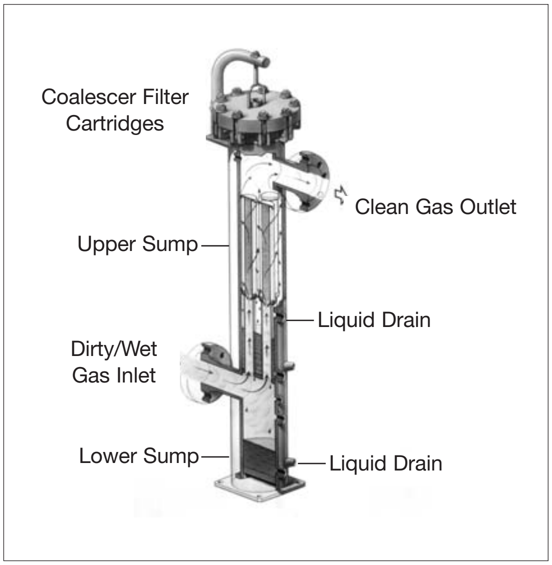


Table 1 summarizes each of these technologies and provides guidelines for proper selection. As you can see, for systems containing very fine aerosols, under 5 µm, a coalescer should be selected. Removing very fine aerosols from gases results in major economic, reliability, and maintenance benefits in compressor systems.

Table 1: Types of Liquid/Gas Separators

Technology	Droplet Size Removed
Gravity Separator	Down to 300µm
Centrifugal Separator	Down to 8–10µm
Mist Eliminator Pad	Down to 10µm
Vane Separator	Down to 10µm
High Efficiency L/G Coalescer	Down to 0.1µm

Formation of Fine Aerosols

There are several different ways that very fine liquid aerosols can get into a gas stream.

- Condensation from a saturated vapor,
- Atomization (spray effect through a flow restriction) and,
- Liquid reentrainment.[8]

Recent studies on aerosol size distribution in a natural gas stream have identified that significant quantities of droplets below 5 microns are the norm whenever choke valves and other restrictions are present[9] or when vapors are at their dew points.[10] The measurements shown in Figure 3 were performed to determine concentration ofliquid aerosols in natural gas stream sampled downstream of vane separators (combination of gravity separator and horizontal filter barrier and equivalent to a mist eliminator pad). Results show that in many cases, large quantities of aerosols can go through this type of separator because the droplets are too small to be trapped by these separation devices. As a result, a liquid/gas coalescer should be the technology of choice whenever high recovery rates are required to protect downstream equipment or to recover valuable liquid products.

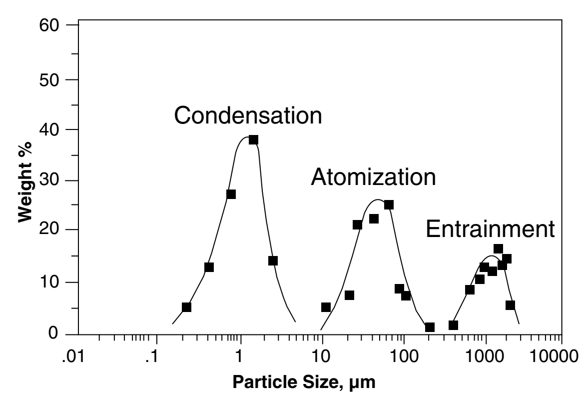
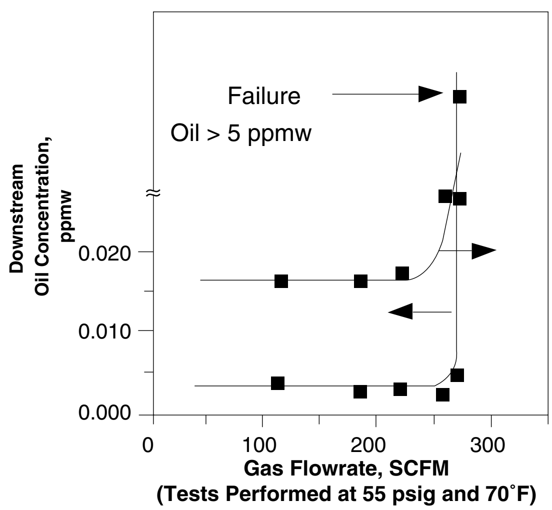


Figure 3: Aerosol Sizes

It is important to note that a coalescer is different from a filter in that it performs both filtration of fine solid particles and coalescence of liquid aerosols from a gas stream. The sizing and rating criteria for coalescers, as it pertains to liquids removal, is very critical to the ultimate performance of the coalescer. An undersized coalescer will result in continuous liquid reentrainment, very low liquid separation efficiency and will be vulnerable to any process changes. The critical nature of coalescer sizing is illustrated in Figure 4 which shows that coalescer performance can drop very rapidly once the coalescer is challenged by too much liquid (either because of high aerosol concentration in the gas stream or because of a high gas flowrate). This marks a dramatic departure from most other separation equipment whose performance gradually diminishes as it is pushed passed its rated maximum.

Figure 4: Coalescer Efficiency Change vs. Gas Flow Rate



Traditional means of coalescer performance validation is the DOP (dioctylphthalate) test.[11] In this test, a monodispersed aerosol of 0.3 µm diameter is continuously generated by a condensation of DOP vapor under controlled conditions. When aerosol generation is stabilized (constant particle size and aerosol concentration), the concentration of DOP is measured upstream and downstream of the coalescer by a light scattering photometer. Results are expressed as a percent of DOP penetration at the flow rate used.

Some major drawbacks of the DOP test include:[12]

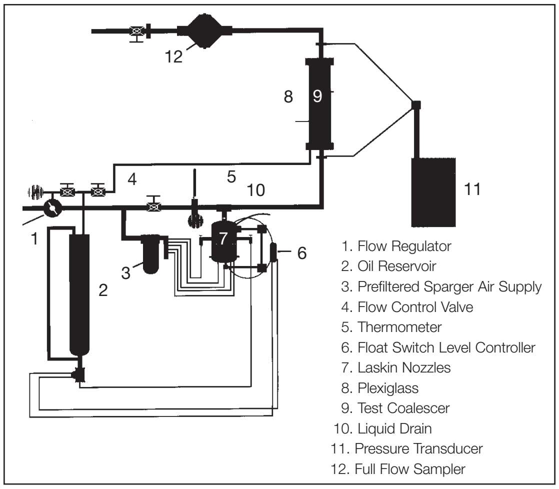
1. The test is performed on a dry or unsaturated cartridge. A dry cartridge, in essence, acts like a sponge, absorbing any liquid which goes through it. What the DOP test does not measure is the coalescer's ability to retain liquids when liquids saturate the coalescer medium and could be re-entrained downstream.

2. This leads to a second drawback; the pressure drop measured across the assembly is underestimated when compared with actual pressure drops across a saturated element. The saturated ΔP is approximately 2-4 times greater than the clean ΔP.

3. The test is performed under a partial vacuum where gas properties (density and viscosity) are very different from those prevailing at actual operating pressure. DOP test conditions tend to overstate the efficiency of the coalescer element.

In order to avoid shortcomings of the DOP test, Pall has developed the Liquid Aerosol Separation Efficiency (LASE) test. This test was developed solely for the purpose of measuring coalescer performance in a compressed gas stream under conditions more similar to those found in a refinery or a gas processing plant. The system used for this test is schematically represented in Figure 5.

Figure 5: Liquid Aerosol Separation Efficiency Test Schematic



The LASE test differs from the DOP test in the following ways:

1. It gives a more accurate and meaningful measure of efficiency.The DOP efficiency essentially tells you what percent of 0.3 μm dioctylphthalate droplets will be removed by a dry coalescer; the LASE test tells you what ppmw of contaminants will be in the gas downstream of the coalescer. In other words, what the LASE test tells you is how much contaminant your downstream equipment will be exposed to.
2. The DOP uses monodispersed (ie. same sized) droplets of DOP, a liquid not commonly encountered in a gas processing or refinery gas streams; the LASE test uses a lube oil which has droplet sizes that range from 0.1-0.9 μm.
3. The LASE test more closely simulates process conditions, by being run on a saturated cartridge and being performed under positive pressure.

Table 2 shows a comparison of the DOP and LASE test.

Table 2: Comparing LASE Test vs. DOP Test

	LASE Test	DOP Test	LASE Advantage
1. Efficiency Rating	ppmw downstream aerosol concentration	% removal of influent 0.3μm particles	Specifies performance independent of inlet liquid loading
2. Test Contaminant	Polydispersed 20 wt. compressor lube oil	Monodispersed Dioctryl Phthalate	Closely simulates actual process contamination
3. Downstream Contaminant Measurement	Full flow membrane sampling of all contaminants	Indirect light scattering of 0.3μm contaminants	Directly measures the amount of all liquid downstream
4. Pressure Conditions	Performed under positive pressure	Performed under vacuum	More closely reflects actual process pressure conditions
5. Cartridge Condition	Performed on saturated cartridge	Performed on dry cartridge	Reflects actual process cartridge service conditions
6 Pressure Drop Measurement	Yields operating saturated cartridge pressure drop	Yields dry cartridge pressure drop	Provides a more useful actual service pressure drop

Design and Its Impact on Sizing

The goal for improving coalescer design is to maximize efficiency while preventing liquid reentrainment. Reentrainment occurs when liquid droplets accumulated on a coalescer element are carried off by the exiting gas. This occurs when velocity of the exiting gas, or annular velocity exceeds the gravitational forces of the draining droplet.

We earlier discussed the importance of correct coalescer sizing. In designing and sizing a coalescer, the following parameters must be taken into account:

- Gas velocity through the media,
- Annular velocity of gas exiting the media,
- Solid and liquid aerosol concentration in the inlet gas, and
- Drainability of the coalescer

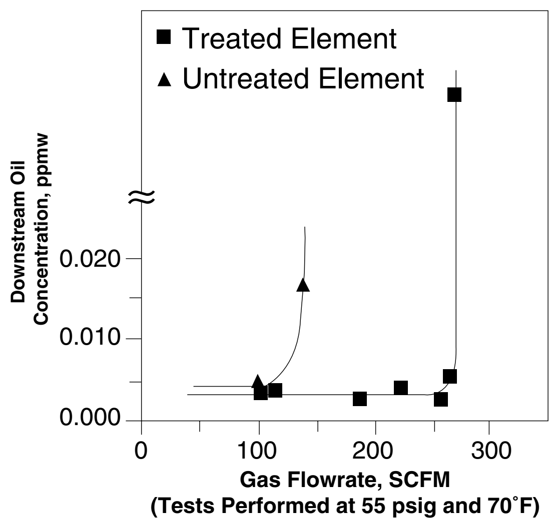
Each of these factors with the exception of the inlet aerosol concentration can be controlled. At a constant gas flow rate, media velocity can be controlled by either changing the coarseness of the medium's pore structure or by increasing or decreasing the number of cartridges used. The coarser the medium, however, the less efficient the coalescer will be at removing liquid.

At a constant gas flow rate, the exiting velocity of the gas can be controlled by increasing or decreasing the size of the vessel or the space between the cartridges.

Drainage can be improved by either selecting low surface energy coalescer materials or by treating the coalescer medium with a chemical that lowers the surface energy of the medium to a value lower than the surface tension of the liquid to be coalesced.[13] Having a low surface energy material prevents liquid from wetting the filter medium and accelerates drainage of liquids down along the medium's fibers. The liquid coalesced on the fibrous material falls rapidly through the network of fibers without accumulating in the pores where it would otherwise be pushed through by the gas and be reentrained. Figure 6 shows the effect that a chemical treatment can have on a coalescer. It shows that the maximum flowrate of a chemically treated cartridge is more than twice that of a similar cartridge that is not treated.

One can conclude from these design parameters that a large housing with a large number of cartridges that have very fine pores would easily eliminate any liquid problems you may encounter in a gas stream. Obviously, the costs associated with such a vessel is very high. As vessel size and cartridge quantity are reduced so is the probability of reentrainment and poorer removal efficiency. In addition, as the assembly size decreases, the pressure drop increases which can result in increased operating costs. So, an optimization is required. When evaluating a coalescer assembly, make sure that all of these parameters are taken into consideration when the assembly is sized. A coalescer is best used in conjunction with a knockout drum or other impingement separator.

Figure 6: Effect of Chemical Treatment on Coalescer Performance



Field Testing For Liquid/Gas Coalescers

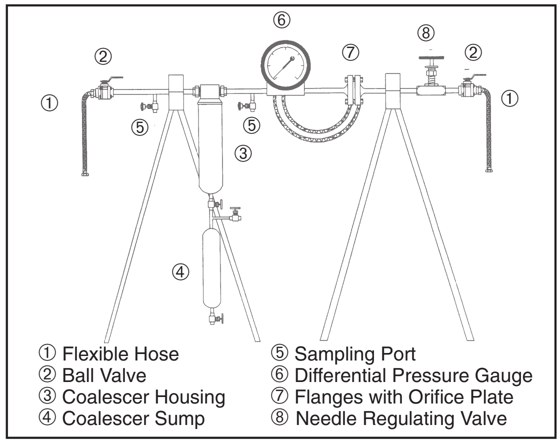
Field testing a gas stream where liquids need to be removed can provide the following information:

1. the amount of liquid in the gas,
2. the ability to efficiently coalesce liquids, and
3. the amount of solid particulate matter present.

As a result, accurate sampling becomes critical. It is very important to measure accurately gas flow rates through a test coalescer cartridge to determine the amount and the nature of the liquid present in the gas.

Figure 7:
Schematic of Pall LG Coalescer Test Stand
(figure 7 on right)

For that purpose, a complete test kit has been designed to perform side stream liquid/gas coalescer testing. This test kit is shown in Figure 7. It includes: (1) a coalescer housing for one cartridge connected to an independent sump by a small ball valve; (2) an orifice flowmeter downstream of the coalescer housing that includes flanges, orifice plate and differential pressure gauge; (3) a needle valve to regulate the flow of gas through the coalescer housing; (4) two sample ports, upstream and downstream of the coalescer housing, to which two of the gas test kits can be hooked up simultaneously to analyze influent and effluent gas quality; and (5) two long flexible stainless steel hoses connecting the test kit to the main gas line and the discharge line.



Test Procedure

Before going on-site for a field test, the plant is contacted to obtain system conditions (pressure, temperature, gas flow rate, type of gas and if possible liquid concentration in the gas stream). Based on this information, an orifice plate is selected to measure gas flow rates in the range indicated. The orifice is also selected to minimize pressure drop so that gas condensation and hydrate formation is not induced.

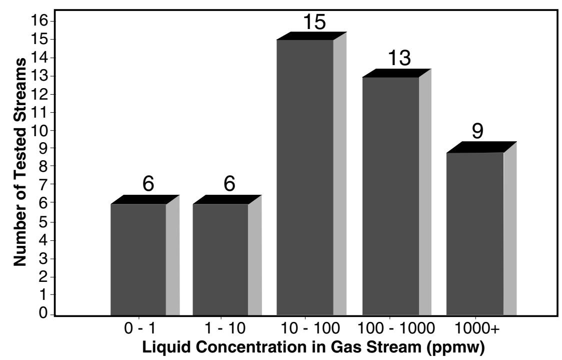
After putting the side stream test kit on-line, the flow rate is adjusted below the critical flow rate, so as not to get reentrained. Once the coalescer cartridge is saturated, test membranes are inserted in the test jigs upstream and downstream of the coalescer housing, the sump is emptied of any liquid that may have been accumulated during the cartridge saturation period, and the actual test begins.

At the end of the test, the volume of liquid accumulated in the sump is measured and collected in a sample bottle for subsequent lab analysis. Test membranes are also collected to determine the amount of solids suspended in the gas and for qualitative identification of the solid contaminants. Liquid aerosol concentration is determined from the amount of liquid coalesced and the quantity of gas sampled.

Field Test Results

The results of field tests on 49 gas streams (natural gas, carbon dioxide, hydrogen and fuel gas) in both gas processing plants and refineries show that significant quantities of liquid are present in most gas streams. Figure 8 summarizes these results of tests. Of the 49 streams tested, over 85% (43 out of 49 tests) had liquids concentration greater than 1 ppmw. This concentration of liquid can result in significant rotating equipment problems and can contribute to poor process operations in an amine contacting unit.

Figure 8: Field Test Results of Gas Streams in Refineries and Gas Processing Plants



Conclusions

1. Selecting gas/liquid separation technologies requires not only knowledge of the process conditions, but a knowledge of the characteristics of the liquid contaminants. Selection should be made based on droplet size, concentration, and whether the liquid has waxing or fouling tendencies.

2. Through an analysis of field data, it was shown that due to the presence of very fine liquid droplets (below 1 micron) in most gas processes, high efficiency liquid/gas coalescers should be recommended whenever high recovery rates are required to protect downstream equipment or to recover valuable liquids.

3. The sizing and design of a coalescer is of critical importance. Once a coalescer is challenged with too much liquid, either because of excessive aerosol concentrations or large gas flow rates, its efficiency will decrease rapidly.

4. The Liquid Aerosol Separation Efficiency (LASE) test is a meaningful performance test of liquid/gas coalescers, as it allows coalescer cartridges to be tested under conditions closely resembling actual operating conditions (saturated element, realistic pressure drops and gas properties (density, viscosity).

5. A surface treatment of the coalescer medium improved liquid drainage in the fibrous materials and decreased by 50% the number of cartridges required to handle a given flow.

6. Field testing has demonstrated that significant amounts of liquids are present in gas stream in refinery and gas processing plants.

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