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DEMYSTIFYING PERFORMANCE RATINGS

Before selecting a coalescer, it's important to understand how they work and how they are rated

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Engineers working in the chemical process industries (CPI) sometimes have to deal with aerosol contamination issues in which liquid-gas coalescers are routinely employed. For example, liquid-gas coalescers are used to protect compressors, liquid-gas contactors, turbines, low-NOx burners, metering and instrumentation stations, and for many other applications.

Choosing the right coalescer type can be a confusing task as many of the equipment-supplier claims can be difficult to understand without more background information on how the products are rated. This article supplies this information and explains how the commonly used rating procedures can affect the performance claims output.

For evaluating a coalescer efficiency rating, it is important to have the test procedure specified and consider the different test options, as they will affect the rating. Furthermore, the same coalescer can give different performance ratings depending on the test method used.

This article compares the different test methods commonly used to rate liquid-gas coalescers, including the DOP [*1*], sodium chloride [*2*], ANSI/CAGI [*3*] and the liquid aerosol separation efficiency (LASE) test [*4*]. A review of how vertical liquid-gas coalescers operate is also presented, including key model features of media velocity and annular velocity as they pertain to test conditions.

Both the DOP and the sodium chloride methods provide information only on the media capture efficiency and do not take into account many of the factors associated with how a liquid-gas coalescer operates. The ANSI/CAGI test is a marked improvement operating under oil-saturated conditions, with a poly disperse inlet particle size distribution. The LASE test takes the evaluation to a further degree by increasing the "challenge" load (inlet concentration) to > 1,000 ppm, and also taking into account the annular velocity and using a full flow sampler to eliminate any side stream bias.

COALESCER BASICS

As mentioned above, there are a number of methods that have been applied to evaluating liquid-gas coalescers in a laboratory setting. In order to understand how the test procedures affect the performance ratings, it is first necessary to have an understanding of how liquid coalescers operate.

Vertical liquid-gas coalescers

Figure 1 depicts a vertical high-efficiency liquid-gas coalescer system. Inlet gas with liquid aerosol contamination enters at the bottom of the housing into a first-stage knockout section. Here any slugs or large droplets (> 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 ranges from 0.1 to 300 μm, and after passing through the coalescer medium, is transformed into enlarged coalesced droplets ranging from 0.5 to 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.

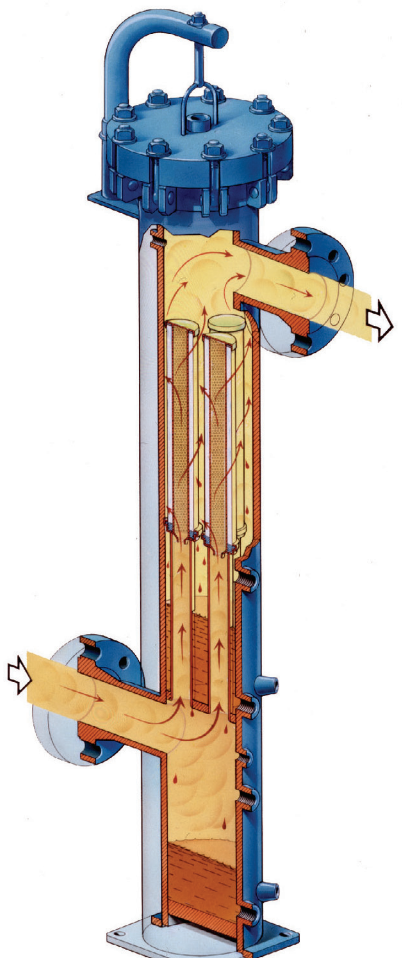

FIGURE 1. Shown here is a typical high-efficiency, liquid-gas coalescer

Four steps have been identified with the mechanism of the formation and removal of droplets in the coalescer medium:

1) Capture
2) Coalescing
3) Release
4) Drainage and separation from media

The formation of the coalesced droplets first involves the capture of the small aerosols onto the fibers of the co-

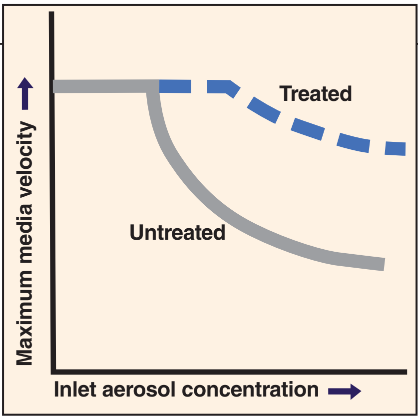

FIGURE 2. This graph shows the effect of surface treatment and liquid loading on media velocity

alescer 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.

Surface treatment. One way to improve the draining of the coalesced liquid drops in the medium is to apply a surface treatment that changes the medium's wetting properties by lowering the overall surface energy. This ensures that both oil and aqueous drops will not wet the surfaces and hence will have lower liquid-fiber attraction forces, thereby allowing better drainage.

Modeling the vertical coalescer

The modeling of the vertical liquid-gas coalescer system can be divided into two basic aspects for performance: media velocity and annular velocity.

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

$$v_{med} = Q_a / NA_{med} \quad \textbf{(1)}$$

Where:
Q_a = actual system flowrate (at system conditions)
N = number of coalescers
A_{med} = media area for one coalescer
Q_a is obtained from the standard system flowrate, Q_s:

$$Q_a = Q_s Sg \rho_{air,stp} / \rho_g \quad \textbf{(2)}$$

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.

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 2 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.

Annular velocity. The annular velocity (v_{ann}) is defined as the actual flowrate divided by the annulus area:

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

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

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

Where:
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 to 2.2 mm and will be mostly influenced by the interfacial tension, which is significantly affected by the liquid-gas types, 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 upward in the opposite direction.

As the gas leaves the coalescer cartridge and travels upward in the annulus, it contributes to the total flow,

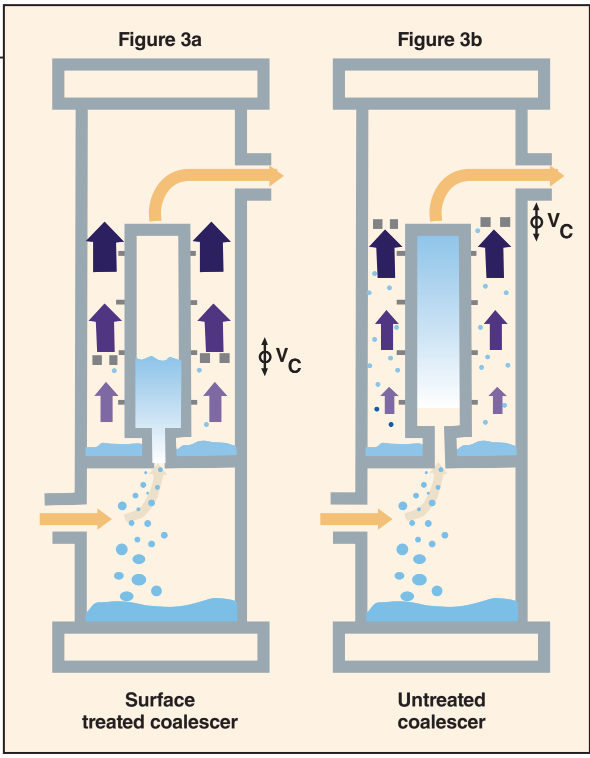

FIGURE 3. Surface treatment of the media reduces the coalesced droplets present in the annulus above the drainage point at the bottom-third of the coalescer cartridge. As a result, treated coalescers (a) can have annular velocities greater than the critical value for re-entrainment, whereas this is not the case for untreated coalescers.

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.

Once the coalesced droplets are formed, they immediately drain vertically downward in the coalescer-medium pack. 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 (Figure 3a). Once the coalesced droplets are released to the annular space they are subjected 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 (v_c).

The use of a surface treatment on high-performance vertical liquid-gas coalescer cartridge systems has been proven to significantly enhance performance by allowing higher flowrates or smaller housing diameters compared to untreated coalescers [*5*].

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 (Figure 3b). 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 permits 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.

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:

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

where k_a is the annular velocity enhancement factor due to drainage.

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:

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

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:

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

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 3. 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.

LABORATORY TEST PROCEDURES

A description of laboratory methods that have been reported by a number of gas-filter and coalescer manufacturers and their relevance to actual field operation is provided below.

DOP test

An organic liquid, dioctyl phthalate (DOP), is first vaporized by heating and then cooled down, allowing the DOP to condense and create a nearly mono-disperse drop-size distribution at 0.3 µm. A portion of the aerosol mist created is mixed with carrier air and flowed through a filter disc used

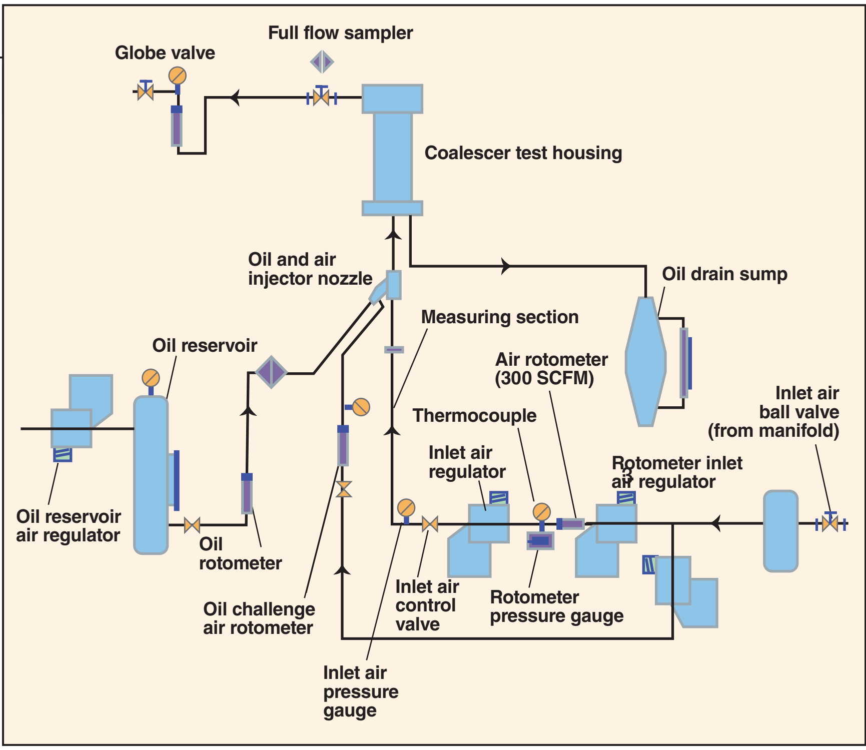

FIGURE 4. The schematic of the liquid aerosol separation efficiency (LASE) test

as the test sample at a controlled flowrate with an aerosol concentration of 100 ± 20 µg/L (~ 77 ppm). Typically, the test sample is a filter disc with an area of 100 cm^2 and is challenged at a flowrate of 32 L/min. The inlet and outlet of the test sample is analyzed for aerosol content using a forward light-scattering photometer.

The test is run on clean, dry filter samples and at minimal pressure to assure sufficient flow with the outlet at atmospheric pressure. Results are measured as percent penetration on a scale setting of down to 0.001% or even to 0.0001%. Values are commonly reported as percent removal at 0.3 µm, with percent removal equal to one minus the percent penetration.

Advantages. The DOP test is an industry standard used for rating high-efficiency particulate air (HEPA) filters, and standard test equipment is readily available. The test is a reliable and useful way to evaluate the capture efficiency of a filter media under initial use conditions.

Disadvantages. The test conditions are not representative of field conditions. The aerosol pressure is very low, and the challenge aerosol concentration is below that of many typical field applications. The aerosol challenge is also nearly mono disperse and uses a different liquid than would be encountered in actual service. The test is run with a clean and dry filter in service. Also the test sample is a filter disc, and this is not always a good simulation of a coalescer cartridge that can contain pleated media and outer wrap materials. Lastly, the test is not measuring a saturated media that would be expected for a liquid-gas coalescer in service.

Sodium chloride test

An aerosol challenge is created by atomizing a sodium chloride solution into a clean, dry filtered air stream. The water carrying the sodium chloride is vaporized, leaving behind solid salt crystals. The salt particle-size distribution can be varied in a controlled manner by adjusting the sodium-chloride solution strength, the pressure and the air flowrate. The aerosol challenge is passed through a test filter disc (typically 90-mm dia.) used as the test sample.

The test flowrate is adjustable and field-service gas fluxrates are typically used. An isokinetic probe is used to draw off a controlled portion of the aerosol stream and pass it to a laser particle counter. The concentration of the aerosol stream is maintained above 106 particles per cubic meter and both inlet and outlet air streams are evaluated for particle counts.

Advantages. The sodium chloride test allows for the use of an aerosol challenge that has a varied particle-size-distribution range similar to that encountered under field conditions. The flow per filter area is adjustable and is typically run at conditions similar to actual field use. The test apparatus includes laser particle counters that have improved accuracy over the light scattering methods used in the DOP test. This method has found wide acceptance in many industries, including the microelectronics field, and is a reliable and useful way to evaluate the capture efficiency of a filter media under initial use conditions.

Disadvantages. The test conditions are not representative of field conditions. The aerosol pressure is very low, and the challenge aerosol is made up of only solid particles. The test is also run with a clean and dry filter in service. Also, the test sample is a filter disc, and this is not always a good simulation of a coalescer cartridge that can contain pleated media and outer wrap materials. Lastly, the test is not measuring a saturated media that would be expected for a liquid-gas coalescer in service.

LASE test

The efficiency of liquid-gas coalescers is measured using a test stand configured as shown in Figure 4. The test stand utilizes an assembly consisting of a standard size element installed in a housing of a standard inside diameter. An oil aerosol challenge is generated upstream of the element using an ultrasonic spray nozzle. Performance measurements are taken only after the coalescer assembly differential pressure and sump drainage rate have stabilized, that is, reached equilibrium. The test flowrate is adjusted up to the rated flow of the test coalescer and the annular velocity is also adjusted to representative field conditions by adjusting the test housing diameter.

The removal efficiency of the coalescer is determined by installing a full flow sampler at the outlet of the coalescer assembly. The reason for employing the full flow sampler is to eliminate sampling biases and ensure that all of the downstream oil, both entrained and wall flow, is captured and accounted for. An extraction and analytical analysis are then performed on the full flow sampler to determine the amount of oil that was collected during the test.

TABLE 1: COMPARISON OF DIFFERENT LABORATORY TEST METHODS FOR RATING LIQUID-GAS COALESCERS

Test method	Aerosol type	Inlet aerosol challenge	Test run at saturated conditions	Test run at max. loading	Test run at maximum annular velocity	Outlet sampling method
DOP	Liquid (dioctyl phthalate)	100 ± 20 µg/L of Air (~ 77 ppm)	No	No	No	Full flow
NaCl	Solid (salt)	> 106 particles per cubic foot greater than 0.003 µm	No	No	No	Isokinetic probe
CAGI	Liquid (lube oil)	40 ppm	Yes	No	No	Isokinetic probe
LASE	Liquid (lube oil)	1,112 ppm	Yes	Yes	Yes	Full flow

General description of the test stand. The test stand is supplied with dry air that is prefiltered and coalesced to eliminate any background dirt or liquid aerosols. The oil is supplied to the atomizing nozzle via a pressurized oil reservoir, and the coalesced oil is collected in a sump and measured. It is important to measure the incremental amount of oil that is drained from the coalescer housing throughout the duration of the test. These data are used to determine the actual liquid challenge. Actual system flowrates are monitored and controlled by a regulating valve, and the flowrate is measured with a calibrated rotometer. System pressure, temperature, and differential pressure across the coalescer assembly are also measured.

The inlet to the housing is through the bottom center of the housing. No settling chambers, inertial separators or other attempts to precondition or remove oil challenge before contact with the element is permitted. The minimum air velocity between the atomizing nozzle and the test element inlet, including all parts of the housing, is 80 ft/s minimum (24.38 m/s).

Aerosol generation. A liquid loading system utilizing an ultrasonic spray nozzle is used to generate the aerosols. The oil used for this evaluation is Mobil Corp.'s DTE – 24 lube oil.

The quantity of aerosol (by mass) and size distribution produced by the nozzle depends on the flowrate through the nozzle and the physical properties of the medium being sparged. The varying sized aerosols generated by this system (0.1–1.0 µm) are considered to be representative of what would be typically found in the aftercooler exhaust air from a reciprocating compressor.

Full flow sampler. The full flow sampler is an inline design and contains a flat sheet, non-corrugated Teflon membrane having a removal rating of at least 0.45 µm and a minimum effective area of 0.26 ft^2 (0.025 m^2). The sampler has a baffle plate to guard against direct impingement of oil droplets onto the medium and to provide a uniform flow across the membrane disc. It also has a surface finish, material of construction and design that allow proper extraction and clean up. The inlet and outlet are equipped with Triclover fittings to facilitate installation and demounting. These fittings are sealed when not in use and during extraction procedures to avoid contamination.

Sampler extraction and analysis method. After a test run, the downstream sampling membranes are extracted by laboratory-grade hexane. A pre-weighed quantity of each solvent is introduced into the sampler and allowed to mix for a known period of time. An aliquot of the mixture is removed and analyzed by either an infrared spectrophotometer when Freon is used, or gas chromatography mass spectrometer (GCMS) method when hexane is used as the extracting solvent. The minimum detectable oil level is 0.001 ppmw, based on air at 100°F and 100 psig. The upstream or challenge aerosol concentration is determined by direct gravimetric measurement following the saturation of the test element and stabilization of the saturated assembly differential pressure by measuring the sump drainage oil from the coalescer housing during the sampling period. Subsequently, the actual upstream-liquid-challenge concentration is determined by adding the downstream aerosol concentration to the sump concentration.

Advantages. The LASE test allows for the use of an aerosol challenge that has a varied particle-size-distribution range similar to that encountered under field conditions. The flow per filter area is specified at 100% rated flow. The test conditions are under pressure and the test coalescer is tested for efficiency after it has become saturated with oil. The aerosol concentration in the challenge feed is 1,112 ppm and represents a realistic and difficult field application. The annular velocity is controlled at conditions expected under field conditions also at the maximum velocity per the LASE sizing method as calculated for the test conditions. The sampling technique used is a full flow sampler, and this method allows for more accurate results than sidestream evaluation.

Disadvantages. The test conditions are not completely representative of field conditions, as the test pressure is still lower than typical operating conditions and uses air as the carrier gas and oil as the liquid aerosol.

ANSI/CAGI

The ANSI/CAGI method follows a similar procedure and uses similar equipment to the LASE test as described above, with a few exceptions that are shown here:

1) The aerosol challenge is much lower at 40 ppm

2) The annular velocity is not adjusted to the expected industrial use

3) The downstream sampling uses a sidestream method that first catches wall flow in a small vessel separator followed by a membrane sampler

Advantages. The ANSI/CAGI test allows for the use of an aerosol challenge that has a varied particle-size distribution range similar to that encountered under field conditions. The flow per filter area is specified at 100% rated flow. The test conditions are under pressure and the test coalescer is tested for efficiency after it has become saturated with oil.

Disadvantages. The test conditions are not representative of field conditions. The aerosol pressure is lower than typical operating conditions and uses air as the carrier gas. The aerosol oil challenge is set to 40 ppm, which is lower than many field applications and makes this an easier test to get

TABLE 2: TEST RESULTS FOR A HIGH-EFFICIENCY LIQUID-GAS COALESCER	
Test Method	**Performance Rating**
DOP	99.999% at 0.3 µm
NaCl	99.7% ≥ 0.3 µm
ANSI/CAGI	0.001 ppmw oil downstream
LASE	0.01 ppmw oil downstream

high-efficiency results. The test protocol does not specify the annular velocity, and this will also enable the test to provide high-efficiency results as well. The downstream sampling method uses a wall flow collector and iso-kinetic probe that is not as accurate as using a full flow sampling membrane.

Concluding observations

Depending on the test method used, varying efficiency ratings can be obtained for the same test coalescer. A comparison of the test methods discussed here are presented in Table 1 along with the actual test results in Table 2 obtained using the SepraSol™ Plus liquid-gas coalescer.

The DOP and sodium chloride tests were found to provide information only on the media capture efficiency and were not taking into account many of the factors associated with how a liquid-gas coalescer operates.

The ANSI/CAGI test is a marked improvement operating under oil-saturated conditions, with a poly disperse inlet particle-size distribution.

The LASE test takes the evaluation to a further degree by increasing the challenge load to > 1,000 ppm, and also taking into account the annular velocity and using a full flow sampler to eliminate any sidestream bias.

So for evaluating a coalescer efficiency rating, it is important to have the test procedure specified and consider the different options, as they will affect the rating. As seen in Table 2, the same coalescer gave quite different readings such as a 0.001 ppm outlet using the ANSI/CAGI test, and a magnitude higher outlet of 0.01 ppm when tested under more severe conditions using the LASE test. ■

Edited by Gerald Ondrey

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