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Practical guidelines show how to apply coalescer technology to enhance burner performance

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Federal and state mandated environmental regulations require petrochemical and refining facilities to reduce nitrous oxide emissions drastically. Industry has widely adopted the use of low and ultra-low NO_x burners to accomplish these environmental goals. The new types of burners, however, use smaller diameter orifices that are more prone to fouling. To overcome this limitation, advanced high-efficiency liquid/gas (L/G) coalescers can be used to condition the fuel gas and protect the burners.

The operational mechanisms of high-efficiency L/G coalescer technology are presented including the use of a fluorocarbon surface treatment and its beneficial impact on sizing and performance. Practical guidelines on how to install the L/G coalscers in the plant environment are discussed, and industrial applications for applying the coalescer technology are presented for the refinery and petrochemical industry.

Background. Nitrous oxides (NO_x) are formed during the combustion of hydrocarbon fuels; nitrogen in air is oxidized (thermal NO_x) or nitrogen compounds in the hydrocarbons react with oxygen to form fuel NO_x. NO_x contaminants are problematic; they are a major pre-cursor to ground-based ozone and can pose a health threat. Ozone is formed when NO_x, volatile organic compounds (VOCs) and sunlight combine.

Environmental regulations mandated significant NO_x reductions, starting with the Clean Air Act Amendments of 1990, and in particular, Title 1 (Ozone Attainment) and Title IV (Acid Rain). Various state implementation plans (SIS) have created even more stringent NO_x emission requirements. Initially, California had the most stringent requirement with a 75% NO_x reduction requirement. More recently, the Texas Natural Resource Conservation Committee (TNRCC) has proposed regulations that require eight counties surrounding Houston to lower NO_x emissions by 90% at point sources by the year 2005, based on 1998 measured levels.

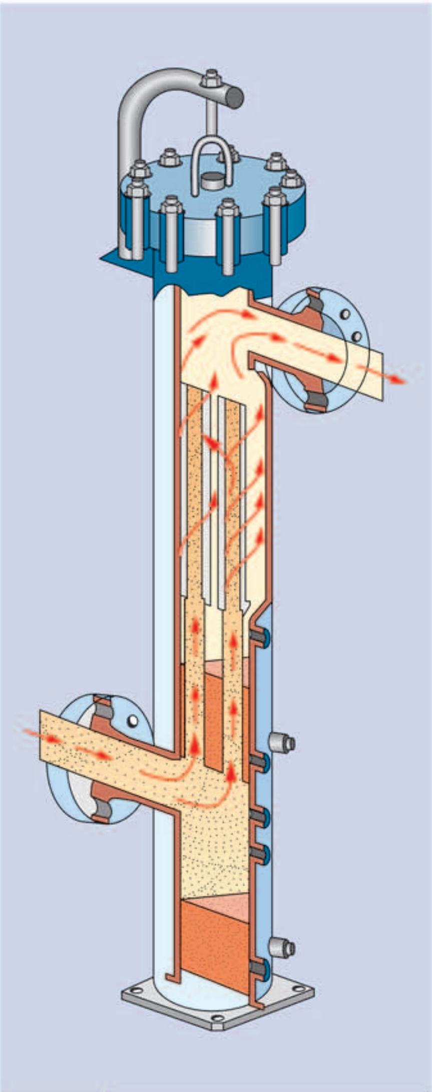

FIG. 1 Cross-sectional view of a high-efficiency L/G coalescer.

Three strategies can be applied to control these contaminant levels and include pre-combustion (advanced burner technologies), post combustion—selective catalytic reduction (SCR)—and hybrid systems. Advances in pre-combustion burners enable significant NO_x reduction, primarily by either lowering temperature or oxygen content.[1,2] NO_x formation is directly related to combustion temperature with almost no NO_x being created below 1,400°F. Some major strategies used to lower NO_x formed in combustion include:[3]

- Limiting excess air
- Staging combustion
- Recirculating flue gas
- Recirculating induced flue gas
- Diluting fuel
- Injecting water/steam
- Reducing air preheat
- Optimizing combustion process
- Installing low and ultra-low NO_x burner technologies.

Over the last 20 years, burner technology has progressed and can be categorized as:

▶ Conventional burners: 100 ppmv (50 ppm with staged combustion)
▶ Low NO_x burners: < 25 ppmv
▶ Ultra-low NO_x burners: < 10 ppmv.

Newer burner designs incorporate different strategies for NO_x reduction. But all use smaller orifices, which are very prone to fouling.

To meet the more stringent NO_x emissions requirements (90% reduction), additional post combustion technology such as SCR may be required. SCR is estimated to be as much as 3–15 times the cost of installing new burner technology.[4] A hybrid approach uses both technologies and can be cost-effective.[5] However, for

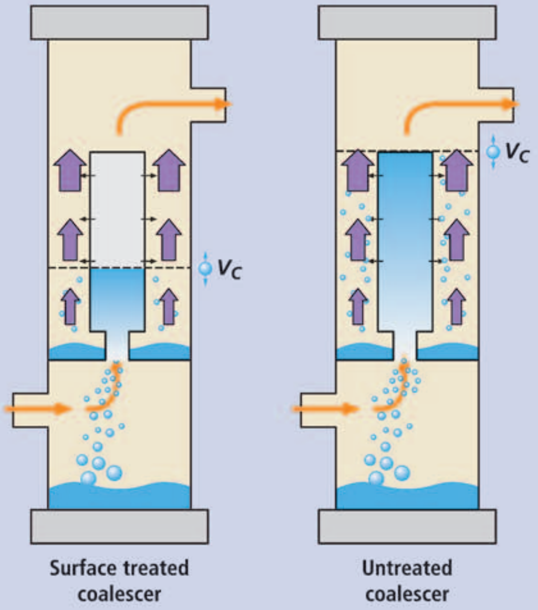

FIG. 2 Effect of surface treatment on annular velocity.

less stringent NO_x reduction requirements, pre-combustion modifications are sufficient. Therefore, burner upgrades have become an industry trend.

When upgrading a conventional burner system, users should consider not only changes for NO_x reduction, but all efforts to maintain unit performance. Collective NO_x control projects also minimize costs, reduce maintenance and maintain plant safety levels. In particular, design details should consider the flame length, additional blowers to recirculate flue gases and upgrade fuel pre-treatment. Other options include improving contaminate removal to protect smaller orifices of newer burner designs. Applying high-efficiency L/G coalescers can improve fuel-gas conditioning and has been adopted in many industrial applications for low and ultra-low NO_x burner protection.

High-efficiency L/G coalescer technology. These coalescers are generally constructed from glass fibers. This material provides a fine porous structure with fiber diameters of a few microns (μ). The small pore size can achieve greater capture and separation of fine aerosols. Separating liquid aerosol with high-performance L/G coalescer cartridge systems is widely used in refineries and gas plants for many applications.

The critical task involving L/G coalescers is protecting compressors, turbo equipment, burner nozzles, amine and glycol contactors, molecular-sieve beds and hydrotreater catalyst beds.[6–8] Traditional separation approaches, including knock-out vessels, centrifugal separators, mesh pads or vane separators, did not meet the end users' requirements for aerosol reduction. High-efficiency coalescers are applied to control sub micron and low-micron sized aerosol contaminants.[9]

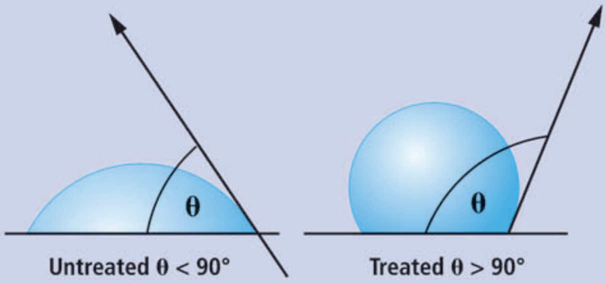

FIG. 3 Contact angle of treated and untreated coalescer medium.

Also, L/G coalescers are separation devices that can be operated at significantly lower flowrates than the initial design. Such units have high turn-down ratios. Separation mechanisms of L/G coalescers are based on diffusion and direct interception, unlike vane separators and mesh pads that rely heavily on inertial separation principles. By using diffusion and direct interception methods, high-efficiency L/G coalescers provide more processing flexibility; they can operate at high turndown ratios (reduced flowrates) that can occur during partial plant shutdowns and upset conditions.

High-efficiency L/G coalescers are used when the inlet aerosol concentrations are 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 L/G can be as low as 0.003 ppmw.[9–11]

A surface treatment on vertical L/G coalescers cartridge systems can enhance performance significantly by allowing higher flowrates or using smaller housing diameters as compared to untreated coalescers.[12]

Fig. 1 depicts a vertical high-efficiency L/G coalescer unit. Inlet gas with liquid aerosol contamination enters at the bottom of the housing into a first-stage, knock-out section. Slugs or larger-sized droplets (approximately >300 μm) are removed by gravitational settling. The gas 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 0.1–300 μm and, after passing through the coalescer medium, is transformed to enlarged coalesced droplets ranging in size between 0.5 mm and 2.2 mm. By flowing from the inside to outside of the coalescer cartridge, gas velocity is easily adjusted in the annulus by selecting the optimum housing diameter to prevent re-entrainment of coalesced droplets

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

Once the coalesced droplets are formed, they immediately drain vertically downward within the coalescer medium pack. Surface treatment can greatly enhance drainage; coalesced droplets are shielded from upward gas flow in the annulus for 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 (Fig. 2). Once the coalesced droplets are released to the annular space, they are subjected to the force from the upward flowing gas. The trajectory of coalesced droplets is modeled on a force balance between gravity settling and drag force created by gas flow. This analysis enables calculating critical annular velocity for re-entrainment.

When a surface treatment is applied on the media, minimal coalesced droplets are present in the annulus above the drainage point at the bottom third of the coalescer cartridge. For an untreated cartridge, coalesced liquids are present throughout the length of the coalescer in the annulus space. The critical annular velocity for re-entrainment is given for the top of the element (Fig. 2).

For the treated coalescer, annular velocities—greater than the critical value for re-entrainment in the portion of the annulus space—are possible since no liquids are present. The maximum annular velocity at the top of the coalescer cartridge is 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 nearly three times greater than the value for an untreated unit. The annulus area is determined by using the maximum allowable annular velocity and designed to prevent re-entrainment with a minimized housing diameter.

L/G coalescer construction—surface treatment.

The L/G coalescer is constructed with an inner rigid stainless steel core around which is placed the active-pleated glass fiber coalescer medium. Using layers of increasing pore size tapers the pore structure in the coalescer medium. The inlet gas first encounters the smallest pores followed by increasing pore size 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, followed by a coarse outer wrap that serves as a drainage zone. The entire coalescer cartridge is treated with an aqueous fluorocarbon emulsion that penetrates through the depth of the glass fiber coalescer medium and drainage layers leaving a thin fluorocarbon coating on all surfaces. **Result:** The surface energy of the coalescer medium is lowered sufficiently to prevent wetting out the coalescer fibers by liquids.

This treatment effectively creates a coalescer medium that is both hydrophobic (water repellent) and oleophobic (oil repellent) as shown in Fig. 3. A droplet is placed on the surface of treated and untreated glass fibers. The degree to which the droplet spreads out on the wetted fiber is measured by the contact angle of the liquid with the solid. For drops that are not strongly adsorbed to the solid surface, the contact angle is greater than 90° while the untreated wetted surface has a contact angle approaching 0°.

Another way to demonstrate this effect is to dip a section of the coalescer medium into a test liquid and compare it to an untreated coalescer section. The treated medium quickly sheds the liquid, while the untreated medium absorbs the liquid, acting as a sponge.

The degree that the liquid aerosols wet out the coalescer fibers has remarkable effects on coalescer performance. One effect is capillary flooding, which is illustrated in Fig. 4. Liquid aerosols entering an idealized cylindrical pore made from untreated coalescer medium allows the liquids to form a continuous layer along the walls of the capillary. As more liquids enter the pore, the liquid coating builds up and eventually blocks the pore completely. Gas pressure then rises in the pore. Ultimately, the drop is ejected from the pore and atomized into several smaller droplets. These newly formed droplets are smaller than the largest drop size possible by coalescence, and are re-entrained by the annular flow.

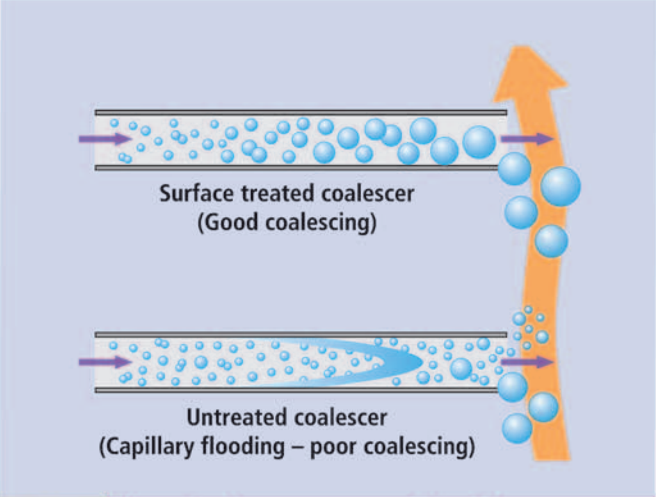

FIG. 4 Effect of surface treatment on media velocity.

A surface-treated coalescer pore behaves differently. The liquids do not wet the capillary walls due to the weak interaction between the liquid aerosols and surface-treated pore walls. Instead, the drops that remain, coalesce with each other throughout the length of the pore and exit the coalescer medium at the largest possible size. These large drops settle by gravity and are not re-entrained. With a surface treated coalescer, the walls of the pore are not wetted out and the capillary cross-section is never blocked; thus, atomization does not occur.

Surface treatment also provides the coalescer with anti-fouling capabilities. Most solids in the gas are associated with the liquid-aerosol droplets. Because a surface-treated coalescer can repel these droplets, solid contaminants do not adhere to the fibers. This anti-fouling capability can extend the medium's service life. Typical field service life for a treated coalescer is from 1 year to 2 years while traditional coalescers last from 2 months to 6 months.

The surface treatment also allows the coalescer to operate with less hold-up volume of liquid; they drain quickly due to the low attraction between the coalescer fibers and liquid drops formed. A less obstructed pathway is created for the gas passing through the coalescer; consequently, lower overall pressure drop is gained. Surface treatment also enhances drainage of coalesced liquids and improves capability to handle higher inlet liquid concentrations and higher annular velocities, and lowers pressure drop.

Modeling L/G coalescer.

The modeling of the L/G coalescer system is divided into two basic performance aspects: media and annular velocities. The other key design consideration is pressure drop. Using more coalescer elements can decrease the pressure drop.

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

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

where: Qa = actual system flowrate (at system conditions)
N = number of coalescers
A_{med} = filter medium area for one coalescer

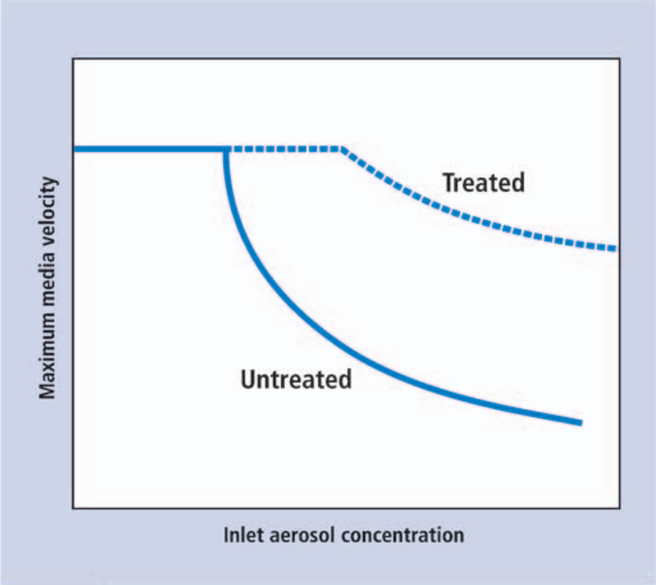

FIG. 5 Effect of surface treatment and liquid loading on media velocity.

Q_a is obtained from the standard system flowrate (Q_s):

$$Q_a = Q_s \mathrm{sg} \rho_{\mathrm{air,stp}} / \rho_g \qquad (2)$$

where: sg = Gas specific gravity
$\rho_{\mathrm{air,stp}}$ = Density of air at standard temperature and pressure
ρ_g = Density of gas at system conditions.

Media velocity is not the actual velocity through the open pores of the media; it is 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 several factors intrinsic to the particular coalescer design and physical properties of the system. Four steps provide a mechanism of forming and removing droplets in the coalescer medium:

1. Capturing
2. Coalescing
3. Releasing
4. Draining.

Formation of coalesced droplets involves capturing the small aerosols onto the fibers of the coalescer medium. The actual coalescing or merging of fine droplets occurs on the fibers, especially at fiber intersections. These coalesced droplets are released from the fiber by the drag force of the gas flow exceeding adsorption energy. This process is repeated through the depth of the coalescer medium until the coalescing process is completed; the largest stable droplet size is achieved. During the coalescing stages, these growing droplets are also draining downward inside the media pack due to gravity.

Surface treatment allows the release and drainage process to proceed at a faster rate, which releases more coalescing sites on the fibers and allows the coalescer to process higher inlet liquid aerosol concentrations.

System conditions on media velocity. The ability of the coalescer medium to perform also depends on the system's environment. Different coalescer constructions will exhibit quantitative differences; yet, they will follow the same qualitative behavior. The media velocity depends 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 Fig. 5 for treated and untreated coalescer media.

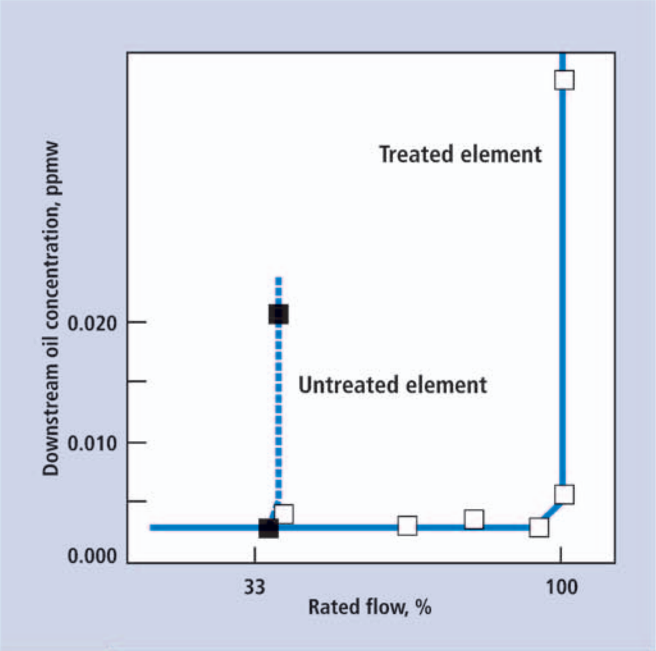

FIG. 6 Laboratory results for treated and untreated L/G coalescer performance.

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 aerosol concentrations, the coalescer medium is limited by drainage and is inversely proportional to the aerosol concentration. Surface treatment does enhance drainage and allows higher maximum media velocities under the same aerosol loading when limited by drainage. The plot of the surface-treated coalescer media is based on a threefold increase in drainage ability. The net effect of the higher drainage with 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:

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

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:

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

where: π = Numerical constant (3.14)
R_h = Radius of the housing
R_c = Radius of coalescer end cap
N = Number of coalescers.

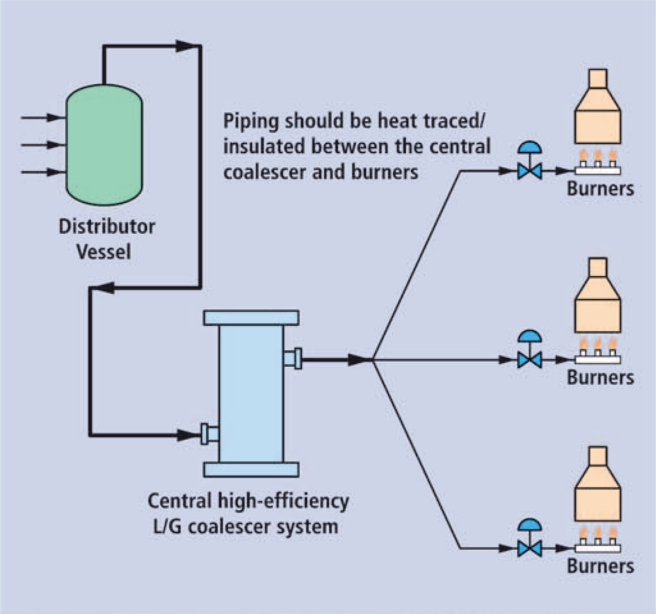

FIG. 7 High-efficiency L/G coalescer—central configuration.

Enlarged droplets exit the coalescer media pack and are assumed to be as large as possible for given flow conditions. Therefore, the coalesced droplet diameter will be the same for any specific design of coalescer cartridge as long as complete coalescence is achieved. If coalescence is incomplete, then calculating the coalesced droplet size must include the degree of coalescence.

In most industrial applications, coalesced droplets will range in size from 0.5 mm to 2.2 mm, and are influenced by interfacial tension which, in turn, is significantly affected by liquid density, and system temperature and pressure. As pressure is increased, gas density will also increase while liquid density is only slightly affected. The solubility of the gas in liquid is enhanced at higher pressures. Such conditions substantially decrease interfacial tension at higher pressure; consequently, significantly smaller coalesced droplets are formed.

Once the coalesced droplet size is estimated, the maximum annular velocity that can be sustained without re-entrainment is calculated. Coalesced droplets will produce Reynolds Numbers (Re) outside of the creep flow regime (< 0.1) and Stokes Law. Instead, a force balance is used as liquid droplets settle by gravity and drag force of gas flowing upward in the opposite direction.

Minimum housing diameter. The housing diameter is determined from the areas of the annulus and coalescer end caps. The maximum annular velocity at the top of the coalescer cartridges is used to calculate the required annular area. The maximum annular velocity [v_{ann} (max)] at the top of the coalescer cartridges depends upon 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:

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

where k_a = annular velocity enhancement factor due to drainage.

For untreated medium, the coalescer cartridge is completely wetted, and coalesced droplets are present at 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 equal to the critical value for re-entrainment:

$$\text{Untreated coalescer:} \qquad v_{\text{ann}}\,(\text{max}) = v_c \tag{6}$$

Surface treatment greatly increases drainage. Thus, annular velocity at the top of the coalescer cartridge is significantly higher than the critical value since no coalesced droplets are 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:

$$\text{Surface-treated coalescer:} \qquad v_{\text{ann}}\,(\text{max}) = 3.1\ v_c \tag{7}$$

Convincing evidence for the enhanced maximum annular velocity given by Eq. 5 has been demonstrated by laboratory tests and is presented in Fig. 6.[9–11] 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.

INDUSTRIAL APPLICATIONS

Burners are used extensively in the petrochemical and refining industries. Applications include furnaces used for crude-oil heating, cracking, reforming and coking as well as boilers, gas turbines, driers and incinerators. To meet tighter environmental regulations, advanced burner technology can be installed on furnace sites. For example, one refinery study found that more than 50% of NO_x emissions were sourced from crude heaters, power boilers and hydrogen reformers.[1]

Contaminants in fuel gas can cause problems with furnace operations. Nozzle plugging causes poor furnace performance, and, in extreme cases, damages the convective sections. At some plants, furnace maintenance is an expensive task, requiring burner-tip replacement or cleaning every few days.

Fuel gas can contain contaminants from various sources. Corrosion products form in process piping and cause fouling by inorganic materials. Liquid hydrocarbons can result in coking at the burner tip and lead to fouling by organic materials. Some contaminants of fuel gas are listed here:

Iron sulfide is formed when H_2S reacts with iron present in piping. It may be carried into the fuel gas along with entrained amine or glycol.

Iron oxides are formed by the reaction of water with iron in piping.

Amines (monoethanol amine, diethanol amine or methyl diethanol amine) are often used to treat fuel gas to reduce H_2S or CO_2 content. Carried-over amine may contain corrosion products or lead to further corrosion in process piping.

Glycol (triethylene glycol) is used to remove water vapor from fuel gas. In some cases, glycol is entrained from the contactor and concentrates in the fuel gas. Glycol can also contain corrosion products and be carbonized at the burner tip.

Water. Fuel gas can contain significant water vapor content that condenses into liquid when the temperature decreases. Condensed water can lead to corrosion of the pipeline and cause burner-tip fouling by iron oxides.

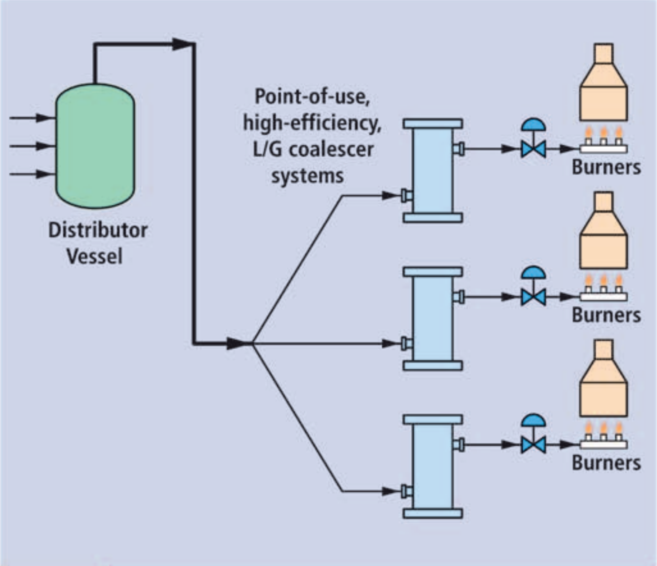

FIG. 8 High-efficiency L/G coalescer—point-of-use configuration.

Hydrocarbon liquids can form by condensation and be carbonized at the burner tip. Heavier hydrocarbons such as lube oil originate from gas compressors. Regeneration of molecular-sieve beds are also a source of heavy hydrocarbon liquids that concentrate in the fuel gas.

Industrial coalescer configurations. Coalescer systems can be configured to treat fuel gas in several ways:

Central location. A single high-capacity coalescer system can treat full flow of the combined fuel-gas source. This configuration minimizes the number of coalescer vessels required and lowers capital investment. Care must be taken, however, to ensure that the gas temperature does not drop when it exits the central coalescer until it reaches the individual furnace banks. In most cases, the piping can be extensive between a central location and furnaces. Therefore, heat tracing and insulation are required to maintain the temperature. Lowering the temperature can cause condensation of aerosols that induce corrosion within the pipeline and eventual plugging of the low NO_x burners (Fig. 7).

Point-of-use. Multiple smaller coalescer systems are placed directly upstream of the furnace banks and provide point-of-use protection. This option can improve protection of the coalescers since the gas will not have an opportunity to cool before entering the furnaces (Fig. 8).

Combined central location and point-of-use. A single high-capacity coalescer system is integrated with a number of smaller point-of-use coalescer units. This option provides maximum protection of the furnaces and will prolong the service life of the point-of-use coalescers. It can also inhibit corrosion within the pipeline between the central coalescer system and point-of-use coalescers.

For old piping or systems known to contain high solids levels in the fuel gas, an additional gas particle filter (GPF) prefilter system is recommended to extend the useful service life of the high-efficiency L/G coalescers. It is also recommended that the upstream piping to the coalescer system is cleaned prior to the L/G coalescer startup.

Coalescer operation. High-efficiency L/G coalescers can reduce the aerosol concentration down to 0.003 ppm in the effluent stream and are typically sized for an initial pressure drop of 2 psid. Experience at a number of petrochemical plants and refineries has shown that the coalescer will usually have a service life of 1–2 years before the cartridges must be changed out. Burner maintenance is also drastically reduced to only scheduled inspections, and the total efficiency of the furnaces is improved. A typical payback period for the coalescer system is less than one year.

Wrap-up. To meet demanding environmental regulations, low and ultra-low NO_x burners are being installed at petrochemical plants and refineries. With new burner technology, feed fuel-gas cleanliness is much higher to prevent plugging the smaller orifices of these devices.

One option is using high-efficiency L/G coalescers to condition fuel gas. Surface treatment on the high-efficiency L/G coalescers can offers substantial benefits. For example, a smaller unit can be used for a given flowrate or larger flowrate for a given coalescer system. Such units offer lower pressure drop and longer service life. **HP**

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