

Landfill Gas Treatment Systems

Getting the gas ready for conversion to energy



BY GREGORY P. MCCARRON AND JEFFREY L. PIERCE

Prior to conversion, limited treatment is required for direct use of landfill gas (LFG) in boilers or engines. Primary treatment steps may include dehydration and filtration to reduce moisture and particulates, as well as hydrogen sulfide and/or volatile organic compound (VOC) removal.

Advanced treatment is required to produce high-BTU gas for injection into natural gas pipelines or production of alternative fuels. Advanced treatment steps provide additional LFG processing and may employ multiple cleanup processes. The type of advanced treatment depends on the constituents that need to be removed for potential end use. This article describes the different approaches and technologies applicable to primary and advanced treatment options.

Primary Treatment

Electric power generation is the most widely applied landfill gas-to-energy (LFGE) technology in the United States. Microturbines, reciprocating engines, combustion turbines, steam cycle, and combined cycle power plants have been

successfully used to convert LFG to electricity. Medium-BTU gas sale is the second most widely applied LFGE technology in the US. Medium-BTU gas projects usually provide limited treatment prior to conveying the LFG through a dedicated pipeline to an end user.

Microturbines, reciprocating engines, combustion turbines, steam cycle, and combined cycle power plants have been successfully used to convert LFG to electricity.

Electric power and medium-BTU gas projects employ primary treatment steps, as necessary, to condition the LFG prior to use. Primary treatment steps, including dehydration, filtration, hydrogen sulfide removal, and VOC removal, are discussed below.

Dehydration

Typically, LFG is saturated with water vapor within the relatively warm landfill. When extracted and subjected to relatively cool temperatures outside of the landfill, some of the water vapor in the LFG will condense and form liquid water or condensate. Condensate must be managed, or prevented from forming, throughout the entire LFG process. Of most importance, liquid water cannot be allowed at the burner tip or at an engine's fuel valve.

The simplest and most cost-effective method to prevent condensate from forming, after pressurization or compression of LFG, is temperature control. This approach is used by many electric power projects and a few medium-BTU projects. LFG is almost always cooled after pressurization or compression. The combination of pressure increase, and the subsequent cooling to close to ambient temperature, results in an LFG that is saturated with moisture.

Condensation downstream of the cooler can be avoided by setting the temperature of the LFG exiting the cooler above its dew point temperature (so that the temperature of the LFG in the downstream piping does not cool below its dew point), or by installing a LFG re-heater or heat tracing on the downstream piping (to prevent the LFG temperature from falling below the cooler's LFG outlet temperature). Pipe insulation is employed in any of these cases. Setting the LFG

Typical dehydration systems lower the dew point of the LFG to 40°F and then re-heat the LFG to at least 20°F above the dew point. Typical equipment includes a reheat gas-to-gas heat exchanger, a chilled glycol-to-LFG heat exchanger, and a condensate knock-out.

temperature exiting the cooler higher than its dew point is often not possible due to temperature constraints imposed by the LFG use.

A typical dehydration system for LFG projects removes most of the moisture in the LFG prior to delivery to the pipeline or onsite use. Typical dehydration systems lower the dew point of the LFG to 40°F and then re-heat the LFG to at least 20°F above the dew point. Typical equipment includes a reheat gas-to-gas heat exchanger, a chilled glycol-to-LFG heat exchanger, and a condensate knock-out. Pipe insulation and/or other heat exchangers maybe needed downstream to ensure that the LFG temperature does not fall below the dew point prior to combustion.

Filtration

Condensate knockouts are typically located prior to the inlet of the compression equipment. Besides managing condensate, most knockouts will contain a stainless steel demister. The demister element typically is designed to remove 10 micron and above particulates, in addition to water droplets. For engine projects, a coalescing filter is also used to provide particulate removal down to 0.3 microns.

Removal of Hydrogen Sulfide

There are numerous hydrogen sulfide (H_2S) removal systems that are commercially available. Typically, the goal for removal of H_2S is to reduce corrosion for power generation equipment, to pre-treat LFG for high-BTU gas processing, and/or to reduce sulfur oxides (SO_x) emissions, associated with LFG combustion. An evaluation of H_2S treatment technologies typically hinges on analysis of life-cycle costs. Some treatment systems have high capital costs, but the operating and maintenance (O&M) costs are relatively low. Other treatment systems have relatively low capital costs, but the O&M costs are significantly higher. H_2S treatment systems must be evaluated on a life-cycle basis to ascertain whether a high-capital cost or low-capital cost system is the best fit for an individual landfill.

H_2S removal technologies are typically grouped per the following process categories:

- Physical Adsorption
- Solid Chemical Scavenging
- Liquid Chemical Scavenging
- Solvent Absorption
- Liquid Redox
- Biological Processes

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The advantage for some of the processes is that regeneration of the scrubbing media can often be accomplished. In other cases, media can be regenerated by changing the media temperature or pressure, or by purging the media with air or a purge gas, to release H_2S or sulfur from the media.

Due to the number of technologies available, only a few examples are provided in this article.

The SulfaTreat process is among the simplest of the H_2S treatment technologies available for LFG applications. The SulfaTreat process and similar processes using proprietary media use a manufactured, granular, iron-based media that can achieve H_2S removal efficiencies of 99% with low or high inlet H_2S concentrations. There are no moving parts and no utility services are required, except for a condensate drain. The system essentially consists of large vessels filled with SulfaTreat media, through which LFG flows. The media chemically reacts with H_2S to form a stable iron pyrite. Systems can be designed with either single vessels (once-through), or in a lead-lag configuration with two vessels.

Iron sponge technology is one of the oldest H_2S removal tech-

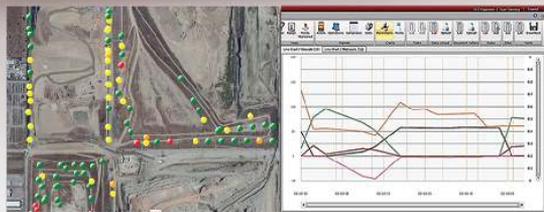


A BioCNG fueling system

nologies available and has been proven effective in LFG applications. The iron sponge technology is similar to SulfaTreat; however, it employs woodchips and wood shavings impregnated with iron oxide as its media. An iron sponge essentially consists of large vessels filled

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with media, through which LFG flows. The iron in the media chemically reacts with H_2S to form iron pyrite.

The LO-CAT technology is an established H_2S removal technology and has been proven effective in LFG applications. The LO-CAT process is a chemical oxidation-reduction process. The LO-CAT process is an aqueous, ambient temperature process that uses a scrubbing tower and a regenerative chelated iron scrubber solution. The product of the system is an elemental sulfur cake, which can be sold or can be disposed in the landfill. Proprietary and non-proprietary versions of the process exist, which vary in the concentration of their iron, type of chelating agent, and/or the supplemental chemicals employed. The LO-CAT process has high capital cost and low O&M cost, as compared to the media-based processes, and tends to be more cost-effective at higher loading rates.

Removal of VOCs

VOCs, and often more specifically volatile organic siloxane compounds (VOSCs), sometimes need to be removed from LFG. VOCs in LFG are gases within gases. VOCs cannot be filtered out of LFG, since VOCs are not in the form of particulates. Advanced physical operations, including condensation, absorption, and/or adsorption, must be employed.

Conventional dehydration, lowering LFG to a temperature in the vicinity of 40°F, is a marginally effective VOC removal technology. It is believed that VOCs are removed during conventional dehydration primarily through absorption of the VOCs into the condensing water, and to a much lesser extent, due to the condensing of VOCs from a gas into a liquid. Conventional dehydration is relatively ineffective in VOC removal. VOC removal is dependent on the amount of moisture in the LFG, the types of VOCs present, and the effectiveness of post-dehydration moisture separation.

Non-regenerative, solid-media VOC removal systems are based on the principle of adsorption and have been widely and successfully deployed over a wide range of conditions. Non-regenerative systems employ single-use media. The media adsorbs VOCs onto its surface until the media's adsorption capacity is exhausted, as evidenced by the breakthrough of VOCs in the LFG at the outlet of the media vessel. The media is then replaced with

as an initial step. The life of the media and its treatment efficacy is improved by dehydration and reheating. LFG relative humidity should be limited to less than 50% and its temperature limited to less than 100°F. Non-regenerative systems are commonly used to treat LFG for use in microturbines, small reciprocating engine plants and to "polish" gas that has already received initial VOC treatment.

Regenerative VOC removal systems can rely on absorption or adsorption. In the absorption process, undesirable gases are preferentially dissolved, under pressure, into a solvent that circulates through a scrubber tower. Adsorption systems are now infrequently used.

Regenerative solid-media VOC removal systems, like non-regenerative systems, rely on adsorption, but incorporate provisions to allow their media to be regenerated onsite. Prior to the media in an online vessel being exhausted, it is taken offline and the media is regenerated through the application of heat. Once the media reaches a desired temperature, the temperature is held for a period of time, and then the media is cooled by continuing to backflow unheated gas.

The process of adsorption of VOCs at normal LFG temperature, and then driving off adsorbed VOCs at high temperature has led to the name temperature swing adsorption (TSA). The TSA vessels are generally sized to last one day between regenerations. Heat for regeneration is most commonly supplied by an inline electric heater. The gas used for backflow is air, carbon dioxide (when available at a high-BTU gas plant), or LFG (when excess LFG is available). The media employed in these systems is activated carbon (when carbon dioxide or LFG is available), silica gel, activated alumina, or proprietary blends of materials. Regenerative solid-media VOC removal systems are commercially available from a few vendors. While the media in these systems is regenerative, the media cannot be regenerated for an unlimited number of cycles. Media is typically replaced every one to two years.

Production of High-BTU Gas

The most advanced form of LFG treatment is treatment to produce high-BTU gas. The term high-BTU gas is generally synonymous with pipeline quality gas since most high-BTU gas is delivered to pipelines for

sale as a natural gas equivalent; however, high-BTU gas with a somewhat lower BTU content can be used for vehicle fuel, or for other fuel uses that demand a BTU content only close to natural gas. The BTU content of LFG is increased by decreasing its carbon dioxide content. A total of 39 high-BTU plants are currently operating in the US. The three most frequently used carbon dioxide removal technologies are: membrane separation (21 plants), Selexol (8 plants), and pressure swing adsorption (7 plants).

Membrane separation relies on the principle of selective permeation of gases through a membrane. Carbon dioxide is a "fast" gas, which passes quickly through a membrane, while methane is a "slow" gas which passes much slower. The driving force behind gas separation is the difference in pressure on the two sides of the membrane. Membrane modules take the form of aggregated strings of parallel hollow fibers.

The LFG is introduced into the bore of the hollow fibers at a pressure of about 150 psig and exits at the end of the fibers at a somewhat reduced pressure with its methane content enriched, as a result of carbon dioxide penetration through the membrane wall, as the LFG travels down the membrane fiber. Water and hydrogen sulfide are "fast" gases and are also removed by the membrane. Some oxygen is also removed.

Selexol is a Dow Chemical trade name for a generic physical solvent—dimethyl ether of polyethylene glycol (DEPG). Most operators of DEPG plants purchase their DEPG under the name Coastal AGR; however, since the earliest LFG plants used Selexol, the term Selexol has become the common descriptor for DEPG technology. Selexol is a physical solvent which will selectively absorb gases from a mixed gas stream. Carbon dioxide is 15 times more soluble than methane. Water is 11,000 more times more soluble than methane. VOCs are hundreds to thousands of times more soluble than methane.

After pressurization to about 450 psig, the LFG is first passed through a "warm" Selexol scrubber tower to remove VOCs, and then through a "cold" Selexol scrubber

tower to remove carbon dioxide. The first tower's Selexol is continuously regenerated by running the spent Selexol through a stripper tower, where it is depressurized and contacted with a counter flow of air or sometimes with the plant's readily available waste carbon dioxide. The stripper gas from the first tower, and usually the second-stage Selexol waste carbon dioxide, is sent to a thermal oxidizer (although the waste carbon dioxide is sometimes vented to the atmosphere).

The efficiency and effectiveness of the process is improved by recycle of some of the partially processed gas to inter-stage compression of the inlet LFG, and by employing multiple flashes (pressure reductions) of carbon dioxide (including a final vacuum flash). The second-stage Selexol is regenerated through carbon dioxide release by pressure reduction. The target carbon dioxide content for the product gas is 2% with an expected methane recovery of about 95%.

PSA technology is also known as a molecular sieve, and it operates on the principle of selective adsorption of one gas versus other gases. In the case of LFG, a media is selected which adsorbs carbon dioxide but not methane. Selectivity is accomplished by use of a media with a pore space opening, which is sized to admit carbon dioxide molecules into the pore space, but to exclude methane molecules. Regeneration of the media is accomplished by alternating the pressure on the media.

When under pressure, gases tend to be adsorbed on to media surfaces. When the pressure is released, the gas is desorbed. To further facilitate desorption and to remove carbon dioxide from the pore spaces, a vacuum is then applied to the media. The pressure in a PSA in an LFG application generally swings from about 100 psig, to -10 psig. The PSA consists of multiple media vessels to allow for sequenced operation and for regeneration of the vessels in a way which minimizes the loss of methane. The number of beds, equalization vessels, vacuum applied, waste gas

management, and other considerations are proprietary to each PSA system manufacturer. In general, PSA system manufacturers require a TSA pretreatment system for VOC removal. The TSA pretreatment systems are essentially the same as those described above for VOC removal. Waste gas, in the form of gas pulled from the PSA vessel under regeneration, is sent either to the TSA as a regeneration gas, to a thermal oxidizer, or sometimes by vent to the atmosphere (although current practice is to not vent any waste gas and to run all waste gas to a thermal oxidizer). The target product gas concentration for PSA technology is typically 2% with an expected methane recovery of 91 to 93%.

Air Liquide markets a skid-mounted membrane separation system, which incorporates three steps:

1. Pressure swing adsorption (PSA);
2. Activated carbon treatment; and
3. Membrane separation.

The PSA step employs two regenerative vessels, operating in parallel. When one vessel is online, the other vessel is undergoing regeneration. The PSA step removes moisture and VOCs from the LFG.

Activated carbon treatment consists of two activated carbon vessels operating in series. The activated carbon is non-regenerative (single-use). The activated carbon provides further VOC removal.

The membrane modules are arrayed into two stages.

The first-stage membrane array produces a partially purified product gas and a low-methane content, high-carbon dioxide content permeate gas. The permeate gas is waste gas. The waste gas is sent to a thermal oxidizer, either directly, or indirectly through the PSA undergoing regeneration.

The second-stage membrane array produces product gas and a permeate gas. The permeate gas is still relatively methane rich. The permeate gas is recycled to the front of the pre-skid LFG compressors to improve membrane skid efficiency. The target carbon dioxide content for the product gas is one percent with an

expected methane recovery of about 90%.

Removal of carbon dioxide alone is sufficient to meet pipeline quality specifications for BTU content, if the nitrogen content of the inlet LFG is able to be limited to less than 1.5%. If the nitrogen content of the inlet LFG cannot be limited to 1.5%, then it will be necessary to add a nitrogen removal PSA behind the carbon dioxide removal step. A nitrogen removal PSA is essentially the same as a carbon dioxide removal PSA, but it is loaded with a nitrogen selective media. The waste gas has a methane content of about 50%, as compared to a carbon dioxide PSA's waste gas methane content of less than 15%, which allows power generation to be considered as an alternative to disposal in a thermal oxidizer. The addition of a nitrogen removal PSA to a plant will significantly increase capital cost and power consumption and will reduce methane recovery.

In some cases, pipelines may have a ppmv level tolerance for oxygen, while a high-BTU plant typically produces a product gas with 0.1 to 0.2% oxygen. A catalytic oxidization unit can be added at the end of the process chain to virtually eliminate oxygen from the product gas. In a catalytic oxidization unit, a stoichiometric amount of methane is oxidized (combusted), at a relatively low temperature, consuming oxygen with the aid of a catalyst bed. Since combustion produces some water, it is necessary to follow the catalytic oxidization unit with a dehydration unit, to avoid exceeding the pipeline's limitation on water content. A TSA dehydration unit is typically used for this purpose. **MSW**

Gregory P. McCarron, P.E., is a Vice President of SCS Engineers and SCS National Expert on Organics. He has 28 years of progressively responsible experience in solid waste management including waste-to-energy systems, landfill design, and landfill gas systems. Jeffrey L. Pierce, P.E., is a Project Director with SCS Energy, a division of SCS Engineers.