Renewable Energy from Biogas

Ultrasonic technology helps City of Charlotte pursue increased energy from renewable biogas

CHARLOTTE.

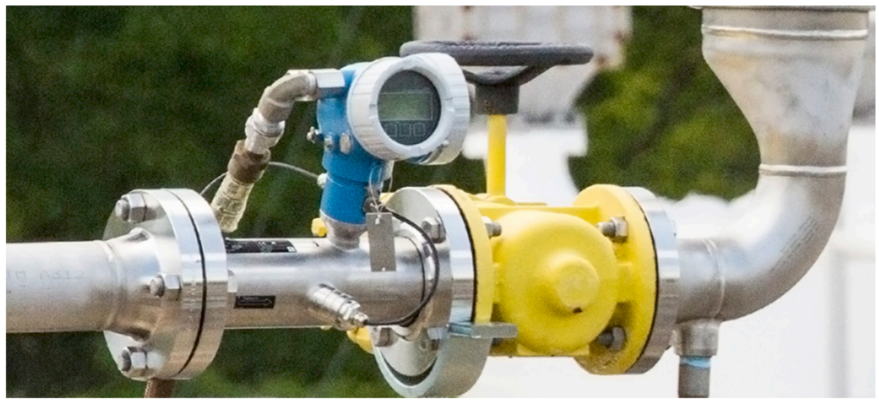
City of Charlotte, NC

The largest public water and wastewater utility in The Carolinas, Charlotte-Mecklenburg Utility Department proudly serves more than 818,005 customers in the City of Charlotte and greater Mecklenburg County -- including the towns of Matthews, Mint Hill, Pineville, Huntersville, Davidson, and Cornelius.

WASTEWATER OPERATIONS
Wastewater Treatment Capacity = 123 mgd
Number of Treatment Plants = 5
Average Daily Treatment = 83.3 mgd
Active Wastewater Service Connections = 242,959
Wastewater Mains = 4,189 miles
Lift Stations = 76

(Facts and figures current through June 30, 2015)

www.charmeck.org



The City of Charlotte, North Carolina, employs five strategically located wastewater treatment plants (WWTPs) to support over 818,000 customers in its service area. The City embarked upon an ambitious plan to generate up to 15% of its largest plant's electrical power needs from a renewable and essentially free biogas energy source. The potential exists to generate even more power in the future through diversification of plant input.

The biogas is created as a by-product of the solid waste treatment process. Currently the City uses biogas energy on a small scale for process heating, but any remaining biogas must be burned through flaring, which is safer and environmentally much less harmful than simply venting excess biogas to the atmosphere.

The City is considering plans to use as much of this energy source as possible, in what will be Charlotte's first Combined Heat & Power (CHP) project. Several obstacles must be overcome before the plan can be realized, including the final design and financial justification. This article describes how the City is identifying and addressing these challenges with the help of ultrasonic flow measurement technology.

The Challenge Anaerobic digesters are commonly used to treat sewage sludge in municipal wastewater plants. These systems are also being used increasingly in waste treatment plants across the industrial spectrum, notably in food & beverage, brewing, chemicals, pulp & paper and large scale agriculture.

The anaerobic digestion process employs micro-organisms; that is, anaerobic bacteria which break down and reduce biodegradable material (biomass) in the absence of oxygen. These digesters are recognizable as a group of large, sealed, egg-shaped or more conventional-looking cylindrical tanks (Figure 1). Unpleasant odors are contained, which is another benefit of the process design. A by-product of the process is biogas, which is rich in methane, and has the potential to be used as an energy source. Wastewater treatment is a 24-7 process, and produced biogas can be considered as an indefinitely available renewable energy source.

Figure 1: Anaerobic digesters in Charlotte, NC, treat sludge and generate biogas, which can be used to generate electricity.

The anaerobic digestion process somewhat resembles the human digestive system. The “good” bacteria of an anaerobic digester may run happily at 95˚F to 98˚F, but significant environmental temperature changes can harm them. Also, the material which the bacteria are required to digest can upset them if it varies dramatically, or if it contains too much of anything which they struggle to digest. The amount of biogas produced and its methane content gives clear indication as to the health of the bacteria. The trend of that data can forewarn of any impending problems.

If bacterial health declines without indication, and no corrective action is prescribed, the process loses efficiency and eventually collapses as the bacterial colony dies. If this occurs, then obviously the volume of waste that can be treated by a facility falls dramatically. In a facility containing four digesters, that represents an unplanned 25% loss of capacity. Some non-municipal facilities may only have two digesters, and so the loss of one means a 50% drop in waste treatment capacity, which in turn severely restricts the upstream processes.

Beyond that, the digester must be completely cleaned out, reloaded with organic material and a new bacterial colony found and seeded. The colony will need some time to multiply, before it can cope with the normal load of the anaerobic digester it is to support. Testimonials indicate that the cost to the operator of a failed anaerobic digester can exceed $500,000.

Typical municipal wastewater has a relatively constant material composition, and therefore the anaerobic bacteria can perhaps run unobserved for long periods of time if their environment is otherwise stable. However, after testing of the CHP facility, the City will consider possible expansion of its raw material input stream to include fats, oils and greases (FOG) that would be accepted from schools, hospitals, restaurants and large public buildings, etc. If this happens, the anaerobic bacteria will be facing additional variables within the feedstock, and constant monitoring of the digester gas will be integral to the control strategy.

No control without measurement

Centralizing untreated solid waste for the anaerobic digestion process produces a sufficient capacity of biogas fuel for a gas engine, which in turn can generate up to one Megawatt of electrical power. The complete project, inclusive of infrastructure modifications, carries a return on investment (ROI) now calculated to be a little over 11 years, due to the impact of some of the cheapest power rates in the country. However, it is normal for renewable energy schemes of this type to have lengthy ROI periods. The calculations in the business plan required certain specific biogas data, but existing measurement devices were lacking reliability.

There is an old adage in process control which says “what cannot be measured cannot be controlled.” The City needed to know the quantity, but more importantly, the quality of biogas that can be reliably produced from their anaerobic digesters from a certain type or combination of feedstock. In the context of the planned gas engine scheme, biogas quality essentially means energy content, or specifically the methane content. Operational control of the planned gas engine will depend upon this. The measurement of biogas flow (Figure 2), and thence volume, and its analysis for methane content, has proven over the years to be highly problematic and expensive—not so much the initial purchase price of the instruments or analyzers, or even their initial installation, but rather the ongoing cost of ownership.

Figure 2: In the past, measuring the flow and methane content of biogas was difficult and expensive. Ultrasonic flowmeters proved to be a better solution.

Biogas leaves the digester at a comparatively low flow rate, at an elevated temperature in comparison to ambient, and typically at or near atmospheric pressure. It is saturated with respect to water vapor, it contains dirt particles, and its composition will vary. Variation in gas composition will increase when the City begins processing FOG in addition to basic sewage sludge.

Because the gas is saturated with water vapor, the slightest drop in its temperature will cause free water droplets to form abundantly. Biogas is primarily methane (typically 55-65%), with a balance of carbon dioxide and water vapor, plus sub-percent levels of hydrogen sulfide (H2S) and other trace gases (notably oxygen, nitrogen and hydrogen). The wetness of the gas, the H2S content and the particulate matter in the gas, create a potentially corrosive condensate that will coat the inside of the pipe and pipework components. Measuring elements for instrumentation exposed to the gas can become fouled and sampling lines for analysis can be become restricted or blocked.

While several flow metering technologies have been used for biogas over the years, Thermal Mass technology (a.k.a. thermal dispersion) dominated the market in this particular application. However, this type of meter is not suited to wet biogas applications. Errors in reading can be caused by changes in gas composition and the presence of condensed water droplets. Mass flow rate is inferred from a single point mass velocity in the pipe cross section, and is thus highly flow profile dependent. Long, straight inlet and outlet pipe runs are demanded to avoid significant measurement error, but are often unavailable. Flow conditioner plates are not a realistic solution because of the wet, dirty nature of the gas.

The solution Since the early 1980s, transit time ultrasonic technology has been used to measure the flow of wet, dirty, low pressure and variable composition refinery flare gas. The technology, in conjunction with temperature and pressure data, can compute average molecular weight of flare gas. The instrumentation commercially available for this specific application is designed with the oil & gas and chemical industries in mind. What was required for the many thousands of biogas applications globally, was such an industry-optimized solution.

The Proline Prosonic Flow B 200 ultrasonic flowmeter (Figure 3) from Endress+Hauser is a better solution for customers in biogas applications, including landfill gas and coal bed methane.

Figure 3: The City of Charlotte installed Proline Prosonic Flow B 200 ultrasonic flowmeters from Endress+Hauser in 2013.

Operation of the B 200 is simply explained. One or two functional pairs of ultrasonic transducers, defined by meter size, are mounted within a meter spool, such that they are located at a fixed angle to the pipe axis, and with their face-to-face dimension precisely known.

In operation, a series of ultrasonic pulses are transmitted almost simultaneously in alternate directions and their individual transit times measured. When the fluid (in this case biogas) is static, then pulse transit times are identical both in the upstream and downstream directions. When flow is present, pulse transit times in the upstream direction increase, and by the same amount, times in the downstream direction decrease. The transit time difference, determined with nanosecond precision, is proportional to flow velocity, and hence by virtue of pipe cross-sectional area, volume flow rate.

The normal uncertainty is ±1.5% of flow reading. Ultrasonic transducers are in a constant state of oscillation at ultrasonic frequency, and as such, their emitting surfaces effectively repel liquid droplets and solid materials very effectively. If upstream and downstream transit times are stored, summed and halved, one gets the average transit time over a distance which, if precisely known, yields a very accurate sound velocity calculation.

With the addition of an integrally mounted PT1000 temperature sensor (Figure 4), the B 200 uses sound velocity to calculate the methane fraction of the gas. This calculation uses a proven relationship between sound velocity, temperature and a methane/carbon dioxide gas mixture. All other trace components of the gas are ignored for the purposes of this calculation, except water vapor which is compensated for.

Figure 4: Typical installation at the City of Charlotte. The B 200 has an integral temperature sensor to help compute the methane fraction of the biogas.

The B 200 software assumes that the gas is saturated with respect to water vapor, and as such, measured temperature and water dew point are one and the same value. Knowledge of the water dew point allows calculation of water vapor content, and the calculated sound velocity of the gas is corrected for water vapor before it is used to determine methane content. This water vapor correction thus yields a pseudo two-component gas mixture of methane and carbon dioxide which is, as described above, accessed via sound velocity and temperature to give a methane fraction determination with a <±2% uncertainty.

The B 200 is a 2-wire, loop-powered device which can be rendered intrinsically safe or explosion proof to Class I Division 1 cCASUus. The pressure of the biogas is either assumed to be constant, or if variation so demands, an external pressure transmitter input can be used via HART Burst mode. When corrected volume flow rate and methane fraction are known, it only requires another stage of calculation using an internationally recognized algorithm to produce net and gross heating values, energy flow and Wobbe Index. For the safe and efficient management of a combustion process, such as a gas engine, this additional data is very valuable to operations staff.

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The result The City of Charlotte purchased, installed and started up its first B 200 in March of 2013. Expected readings for both flow rate and methane content were immediately seen. There have been no requirements for maintenance of the device since installation. The City later purchased the additional meters required for complete coverage of the scheme. Although a single B 200 on the main header or gathering line of a WWTP would provide valuable information toward management of that plant, it would not provide adequate information as to the cause of any decline in output or quality in terms of the gas available to the plant. Only by monitoring individual digester output can the overall scheme be effectively managed.

Conclusion

The Proline Prosonic Flow B 200 from Endress+Hauser is a proven-in-use solution for the continuous monitoring of anaerobic digester gas, providing reliable data for the safe and efficient operation of individual digesters and the downstream combustion process, where additional revenue can be earned from the combustion of biogas to generate electrical energy from this renewable resource.

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