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TABLE OF CONTENTS

AD INDEX

Grasp the Nuances of Level Measurement

The differences in the way devices work can profoundly affect readings

By Andrew Sloley, Contributing Editor

To truly understand what your process is doing, you must understand how you are measuring its performance. Process instruments provide readings on a variety of physical characteristics, including integer measurements (e.g., batches run, items made, bales processed), continuous measurements (e.g., temperature, pressure, flow, level) and discrete measurements (e.g., weight of product in a container). In all cases, the accuracy of the measurement depends upon the device used. Potential production and safety problems from inaccurate measurements and how the device responds to unusual process events also vary with the type of instrument. To illustrate these points, let's look at three common methods for measuring liquid level: differential pressure devices, displacers and floats.

Figure 1 shows a schematic of these devices installed for measuring liquid level. The differential pressure device is placed directly on the vessel. The displacer and the float are put in a stilling well attached to the vessel. The intent of the stilling well is to keep streams entering the vessel from directly hitting the measurement device.

A differential pressure measurement converts a pressure difference into a height of liquid, *h*, assuming you know the density difference between the liquid and vapor:

$$h = \frac{\Delta P}{g(\rho_l - \rho_v)}$$

where *g* is the gravitational constant.

Many people confuse displacers with floats.

In most applications, the density of the liquid is far higher than that of the vapor. Hence, the vapor density often is ignored. However, in some cases, the vapor density can be important.

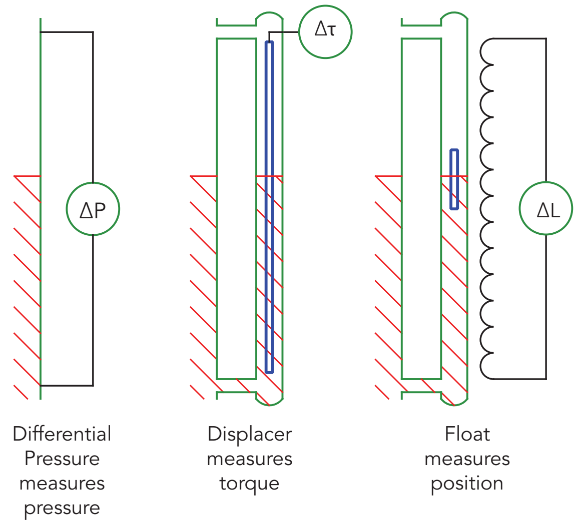
A displacer doesn't measure pressure. Instead, it measures torque, τ, generated by buoyant force. The displacer is a modern application of the phenomenon that led Archimedes to exclaim "Eureka." As the liquid level increases, the displaced liquid appears to make the displacer weigh less. This weight change equals the weight of the displaced liquid. If the density and cross-sectional area of the displacer are known, the change in torque directly translates into liquid level.

Both the differential pressure device and displacer measure a physical variable that requires a value for density to convert the measurement into a level. As long as you use the actual density, the measurement is accurate. If the density assumed is wrong or changes, then the level measurement is inaccurate. Assuming too low a density will give a level less than expected while assuming one too high will lead to the opposite result.

Two extreme cases deserve mentioning.

In foams, densities may be dramatically lower than expected. The foam level may be many times higher than the liquid level. Foam can end up in vapor lines and cause significant downstream problems.

The second extreme case is if the actual density is lower than the assumed density and the liquid level goes above the span of the instrument. In such cases, a level instrument may continue to show a liquid level



LIQUID LEVEL MEASUREMENT
Figure 1. Methods rely on different variables to come up with a reading.

less than 100%; any level changes calculated from the instrument reading are due to density changes in the liquid, not level changes in the vessel. This was a small, but real, contributing factor to the infamous BP Texas City refinery disaster on March 23, 2005. Operators saw changes in level but the liquid level actually was well above the displacer. The changing level reflected falling liquid density as the tower heated up.

Texas City brings up a second point about displacers. They are not the same as floats. The buoyant body in the torque displacer shown doesn't move very much. It isn't floating on the liquid. In contrast, a float eventually will reach the top of the range, even if mis-calibrated.

Figure 1 also shows a float — in this case, a magnetic float without direct contact between it and the sensing element. The signal going to the control system is a direct measurement of the float's position, which isn't necessarily the same as the liquid level. The float's submergence will change depending upon the liquid density. The lower the liquid density, the more the float will sink into the liquid, and vice versa.

Many people confuse displacers with floats. Indeed, one source of misunderstanding in Texas City was lack of appreciation of the differences between these two devices. I've gone into some detail about these differences in a previous column, "Interpret Level Readings Right," http://bit.ly/2N9cHpw, but it's worth briefly reviewing them.

Changes in levels reported with changes in liquid density differ dramatically between these instruments. The error in level reading with changes in density for the differential pressure measurement and the displacer is a percent of the level. For differential pressure and displacer measurements, the reading shifts by a percent of the reading.

In contrast, with a float, errors in readings are a percent of the float dimension. A short float would have small errors. A longer float would have larger errors. Errors in density cause an offset in level readings. The measurement is off by a fixed percent of range set by the float dimension independent of the level reading.

The most effective plant engineers understand the physics of what's being measured by the instrument. They know how this gets converted to common control room readings. And they grasp how to use this knowledge to troubleshoot and run the plant better.

Optimize Your Process with Interface Level Measurement

Monitoring vessels with immiscible liquids pose numerous challenges

By Magnetrol

Interface or multiphase level measurements exist throughout oil and gas streams as well as petrochemical/chemical. While level measurement technologies have come a long way in effectively measuring liquids and solids, multiphase level measurement is the biggest challenge and opportunity.

Process optimization and increased uptime still is achievable in many separator applications through reliable, best-in-class level technology. This article reviews interface challenges, the current technologies being used for interface, and field experience in various applications that deliver optimal results.

INTERFACE CHALLENGES

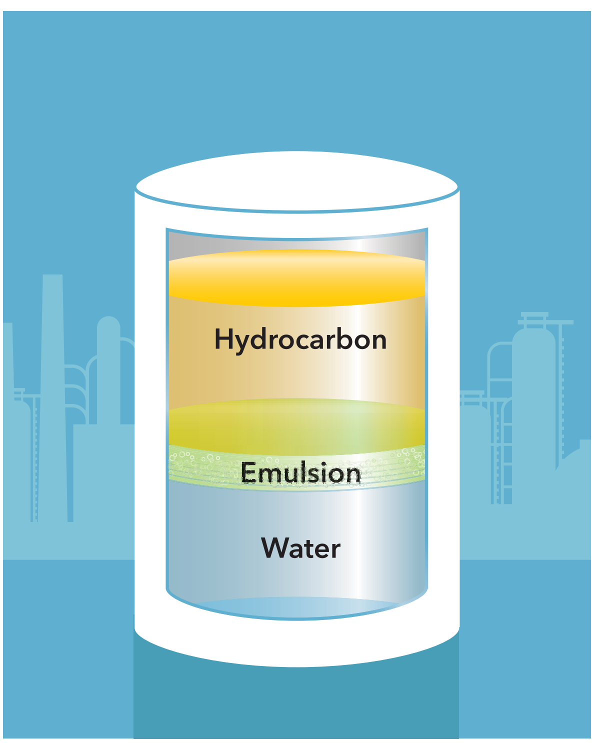
The need for interface measurement arises whenever immiscible liquids — those incapable of mixing — reside within the same vessel. The lighter medium rises to the top and the heavier settles at the bottom. In oil production, for example, water or steam is used to extract oil from a well. Well fluids then route to production separators (Figure

UPSTREAM APPLICATION
Figure 1. Interface level measurements monitor upstream separators where the primary constituents settle as a hydrocarbon over water.

1) where they settle into their primary constituents as a hydrocarbon over water.

Interfaces can form between liquids and solids, liquid and foam, liquid and gas; but the emphasis here will be concentrated on liquid-liquid interface (often with a vapor space above the top/lighter liquid).

Immiscible liquids meet along an interface layer where they undergo some amount of emulsification. This emulsion layer (also referred to as a "rag" layer) may form a narrow, distinct boundary, but more frequently it is a broader gradient of the mixed liquids (Figure 2). Generally, the thicker the emulsion layer, the greater the measurement challenge.



LIQUID LEVELS
Figure 2. Multiphase level often includes a hydrocarbon liquid on top, an emulsion (rag layer) middle and water bottom.

While monitoring the top, or total level, is critical for safety and overfill prevention, knowing the position of an interface is necessary for maintaining product quality and operational efficiency. If there is water in hydrocarbon liquid that's not separated effectively (water carryover), then this can cause processing problems, equipment failures and unplanned shutdowns. If there is hydrocarbon liquid in water, this can result in production loss, environmental fines, penalties and forced shutdowns.

Of all of the level switches and transmitters available, only a handful are suitable for reliable interface measurement. The leading interface measurement technologies include guided wave radar (GWR), buoyancy-based displacers, magnetostrictive, RF capacitance, nuclear/gamma radiation and thermal dispersion. Ideally, the technology used for interface applications shouldn't differ from other level instruments installed at the facility to maintain user familiarity. Standardizing on a technology also helps reduce training, installation and commissioning, maintenance and downtime. Of course, all of these items have an associated cost.

LEVEL TECHNOLOGIES FOR INTERFACE MEASUREMENT

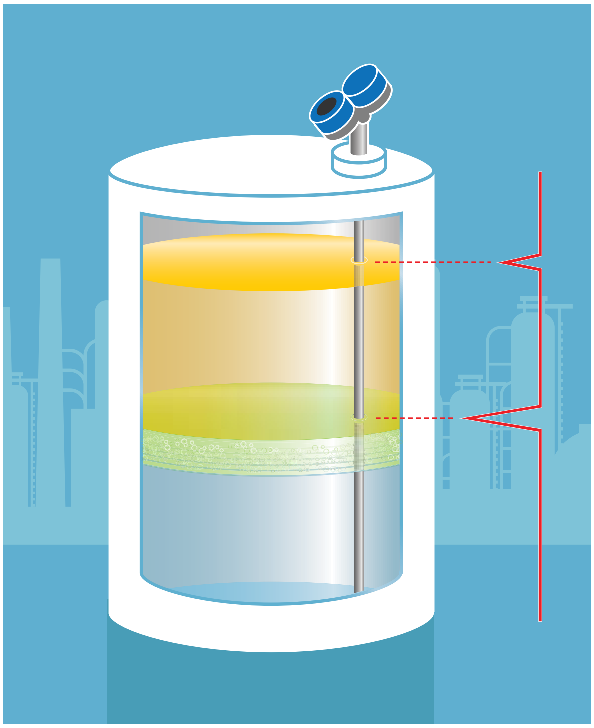
There is no perfect, one-size-fits-all technology for interface applications. Outside

Generally, the thicker the emulsion layer, the greater the measurement challenge.

of reliability, price point and process information, familiarity often plays a pivotal role in determining the level measurement solution. This is particularly true for established technologies such as differential pressure (DP) and displacer-based products.

DP still is the most widely used level measurement technology. However, DP is not a preferred technology for interface. Extensive calibration is required along with assumptions that density (specific gravity) and total level are constant. Using this technology typically results in one inferred interface measurement near the middle of the emulsion layer as opposed to both total level and interface measurement. Variation in the emulsion layer's thickness affects density, which potentially induces significant error.

Another preferred technology with high growth rate is GWR. The ability to use GWR for both total level (potential overfill prevention) and interface applications increases user familiarity greatly, allowing the technology to be applied correctly while decreasing training and commissioning time. GWR, which reports both total level and interface level simultaneously (Figure 3), may have limitations with respect to emulsions, but they can be mitigated with demulsifiers or increasing process



GWR APPLICATION
Figure 3. This vessel uses guided wave radar technology with signal reflections down probe.

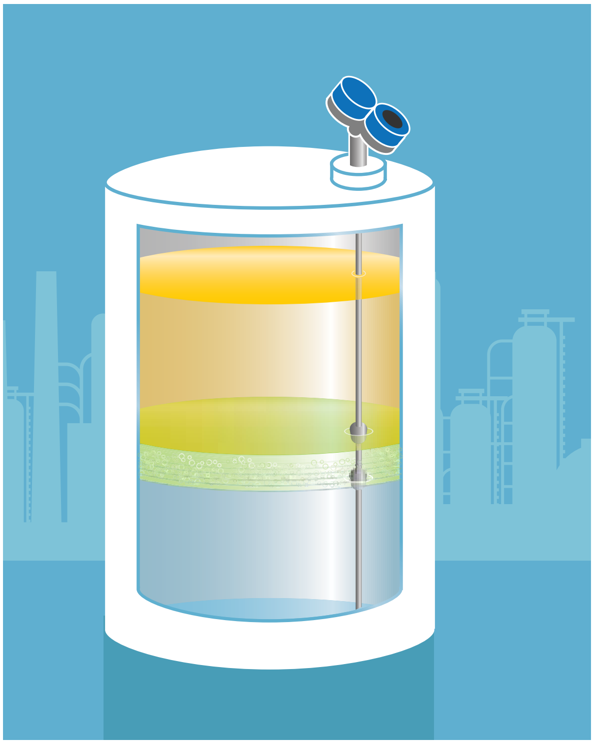
One critical factor when implementing GWR is that the higher dielectric medium must be the bottom liquid.

temperature to assist the separation of heavier hydrocarbons.

One critical factor when implementing GWR is that the higher dielectric medium must be the bottom liquid, which is the majority of cases for water-based liquids versus lower dielectric, hydrocarbon-based liquids. If the higher dielectric medium is on top, then a technology based upon buoyancy principles would be preferred.

Magnetostrictive technology (Figure 4) also is used for interface measurement. It is based on buoyancy principles, and therefore specific gravity-related drawbacks exist, but it has advantages particularly in applications with large or swelling emulsion layers as well as the aforementioned application in which a higher dielectric medium resides on top of a lower dielectric medium. The floats may be weighted to measure the emulsion layer if enough separation exists, or both the total level and interface. Consideration must be taken for solids buildup, such as paraffin or asphaltene adhesion, due to the moving parts.

Other technologies, such as displacers (mechanical) and RF capacitance, historically have been used for interface measurement. Heavy hydrocarbons may present major inaccuracies when coating probes or building up on floats, which can increase maintenance cost and intervals. However, there often is a comfort level



MAGNETOSTRICTIVE UNIT
Figure 4. A direct-insertion magnetostrictive transmitter measures the emulsion layer.

with these technologies that may translate into other efficiencies versus retrofitting newer technologies.

Table 1 presents a brief review of the primary technologies used in interface, along with their strengths and limitations. It is important always to address the density (SG), or API gravity, for technology consideration. High specific gravity (low API), heavy crude oils impact the emulsion layer and potentially add to the maintenance requirements.

TECHNOLOGY	MEASUREMENT	STRENGTHS	LIMITATIONS
Guided Wave Radar	• Tracks top level and near top of emulsion layer • Low dielectric top level and high dielectric bottom level • Direct level measurement, even in low dielectrics, versus inferred (some GWR and other technologies)	• No calibration • No density dependency • Buildup detection and diagnostics • Less maintenance (no moving parts) • Overfill prevention (total level measurement) • Familiar across applications	• Thick emulsion layers and energy lost before bottom • Manufacturer performance variation such as those inferring or bottom following • Plugging potential for coaxial probes
Displacer	• Tracks near middle or average of emulsion layer • Buoyancy forces change with liquid type • Capable of measuring interfaces with higher dielectric liquid on top	• Historical familiarity across application • Switches and transmitters	• Moving parts to maintain • SG dependent • Only interface level or total level and range may be fixed
Magnetostrictive	• Buoyancy-based floats weighted for different levels, including total level and particular bottom of emulsion • Capable of measuring interfaces with higher dielectric liquid on top	• Multi-float (SG) configurations for total level and emulsion layer • Thick or growing/swelling emulsion layers • No calibration typically required	• Moving parts to maintain particularly due to coating • SG dependent • Minimum separation required by physical float dimensions
Capacitance	• Measures near bottom of emulsion layer • Capacitance changes between low/high dielectrics	• Historical familiarity for interface • Less maintenance with no moving parts • Switches and transmitters • Economical price point	• Calibration required • SG/dielectric/viscosity performance variation • Less usage in other applications • Buildup on probe/coating
Nuclear (gamma/ radiometric)	• Nuclear radiation variation through different SGs • Profiles emulsion	• Inferred profile of emulsion layer including thick rag layers • Some types are non-contact to process • Can profile sand and foam for contact-type devices	• Expensive upfront price with additional regulation, maintenance and safety costs • Wall buildup and SG variation can cause errors • Non-contact only on smaller diameter vessels
Thermal Dispersion	• Switch point dependent on calibration • Thermal conductivity differences between liquids	• Economical • Less maintenance with no moving parts or plugging • Foam detection possible • Analog output emulsion tracking	• Switches only • Calibration required • Less familiarity

INTERFACE LEVEL TECHNOLOGY COMPARISON
Table 1. When considering a level technology, it's important to address the density (SG), or API gravity.

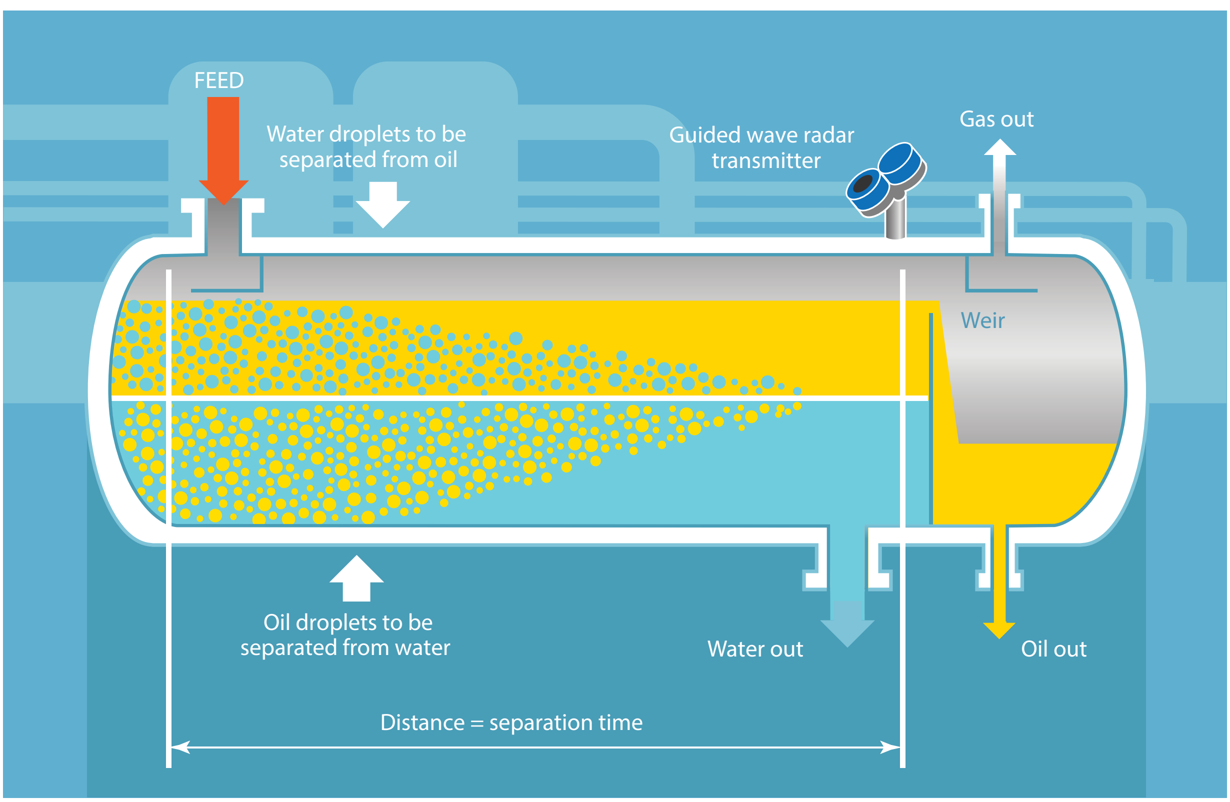
TIPS TO CONSIDER FOR OPTIMAL PERFORMANCE

Numerous interface applications potentially can produce an emulsion layer. Having a reliable level measurement will help optimize processes while increasing uptime.

No matter the technology, optimal installation conditions will assist in maximizing device performance. For instance, when inlet crude oil from a well enters a separator, retention time may be the most important factor to allow for the desired instrumentation performance and, therefore, process optimization.

In other words, if the feed comes into a horizontal separator, the optimal installation location of the level measurement device is farther away from the inlet (closer to the weir) where crude and water separation becomes more uniform. Demulsifiers assist with emulsion breakdown but can be reduced when working in concert with reliable interface level measurement.

The top of the emulsion is an indicator of water present in hydrocarbon and when device performance is maximized, a tighter control of the top of the emulsion layer is possible. With the primary goal of the



HORIZONTAL SEPARATOR
Figure 5. Retention time allows for improved separation and instrumentation performance (note the installation location of the dark blue GWR transmitter).

separator to remove water from the valuable liquid, the level measurement now can allow operation closer or farther away from the weir to optimize separator efficiency and retention time (Figure 5).

If the separator-type is primarily for water storage, with at least a thin layer of hydrocarbon liquid on top, then tighter interface control also will provide a more accurate representation of how much water (only) is present in the vessel. For oil exploration and production (E&P), this improves truck utilization, ensuring full truckloads during water extraction from storage vessels.

Ideal installation may not always be possible on a retrofit, but instrumentation location must be taken into account during separator design.

What is important to consider in any application, regardless of whether it is interface or total level, is what can occur during upset conditions or start-up and shutdown. Most devices may work fine in normal interface operation; however, reliable measurement is required in those upset cases as well:

- When no liquids are present;
- When only one liquid exists (only water or only hydrocarbon liquid);
- When the chamber is flooded (only hydrocarbon liquid and water — no gas phase exists); and
- When multiphase hydrocarbon liquid, water and gas including overfill prevention exists.

The first industry that comes to mind when discussing interface is upstream oil and gas/E&P. The initial challenges begin at the wellhead separators and resonate through the remaining hydrocarbon streams. Aside from this initial separation, a critical interface measurement for unconventional plays using hydraulic fracturing is at saltwater disposal (SWD) facilities.

Interface levels are present in midstream tank farms and storage terminals, downstream boots and desalters at refineries and even petrochemical quench towers in the quench settlers (or quench water separation drums), to name a few. Acceptable solutions exist for many challenges, but productivity has yet to be maximized in applications with thicker, ever-changing emulsions layers.

The key to optimization for interface is solving the emulsion factor. No economical technology accomplishes all three level measurements: the top of the hydrocarbon level (total level), while simultaneously measuring the top of the emulsion (water in hydrocarbon) and bottom of the emulsion (hydrocarbon in water). For the level device, this becomes a multiphase (or three-phase) application.

Other technologies have attempted to solve multiphase measurement but often are uneconomical in doing so. For instance, multiphase flowmeters in upstream processes are positioned against three-phase separators, but these flowmeters can cost hundreds of thousands of dollars themselves.

Nuclear technology can effectively measure the emulsion layer, but nuclear has a similar purchase price along with additional radiation-based regulations and costs. Another option in the market, outside of level, is a multiprobe array based on water percent concentrations. This probe array is costly and requires up to four installation points (including one upstream of the separator).

It is easy to find problems, but less simple to solve them. The success with GWR, specifically for extremely challenging applications, may lead to future enhancements within the technology. GWR effectively measures interface caused by the impedance changes created as the signal travels through the hydrocarbon level into the emulsion. However, as it does not take a great deal of water within a hydrocarbon to make it conductive, this results in an interface measurement near the top of the emulsion only, without detection of the bottom of the emulsion as there is no distinct impedance change through the layer.

Even basic applications with a fairly clean interface can be problematic for some GWR manufacturers that rely on software tricks or inferred measurements in low dielectric hydrocarbons (due to inadequate signal strength). Therefore, evaluate suppliers closely for how they measure interface level in your specific application.

Tackling this multiphase measurement is at the forefront of development as interface level is the most effective means of optimizing separator processes and increasing uptime. ●

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Tune In to 80 GHz Radar

The higher frequency offers improved sensitivity and non-contact measurement in tight spaces.

By Greg Tischler, VEGA Americas

As radar sensors using 80 GHz continue to proliferate, they're being used in applications in which they've never been used before. This certainly is the case for processes that use small tanks or vessels and operations working with products with a low dielec-tric constant (dK). An auto parts manufacturer was up against both — small vessels in tight quarters trying to measure liquid polyethylene (Figure 1).

TIGHT SPACE
Figure 1. It's difficult to measure level of liquid polyethylene in such small vessels with mixers.

Many of our cars now are made from plastics and plastic composites. According to the American Chemistry Council, plastics account for approximately 50% of the volume of a typical vehicle. Manufacturers began using more plastic in cars to overcome the challenges of improving fuel efficiencies and achieving improved vehicle safety.

With smaller antennas, radar sensors now can now be installed in places where they could never go before.

and received by the antenna system. The signals' time of flight from emission to reception is proportional to the distance to the product surface, so the longer the time of flight, the greater the distance. This distance is inversely proportional to the level in the tank. The greater the distance, the lower the level.

The focus of a radar transmitter's microwave beam depends on two things: a radar transmitter's antenna size and its transmission frequency. A smaller antenna will have a wider and less-focused beam. Conversely, a larger antenna will have a narrower, more focused beam. As radars using 80-GHz frequencies have become the standard, larger antennas solely to achieve focus have become obsolete (Figure 2).

A narrow radar beam allows operators to measure in smaller vessels and inside tanks with interior installations such as mixers or heating coils. With smaller antennas, and, by association, smaller process connections, radar sensors now can now be installed in places where they could never go before. For example, VEGA's 80-GHz VEGAPULS 64 achieves a beam angle of only 3.6° using a 3-in. antenna. That same antenna can be shrunk all the way down to ¾ in. while still achieving a beam angle of 14°. This allows radars to be used in tight spaces and still achieve an accurate measurement.

ANTENNA OPTIONS
Figure 2. An 80-GHz radar's focus varies by size of process connection. The larger the antennae, the better the focus.

Process fitting	G ¾"	G 1½"	DN 50	DN 80	DN 80
Beam angle	14°	7°	6°	3.6°	3.3°

BETTER FOCUS AND HIGHER SENSITIVITY

Radar sensors work only as long as they receive a return signal from the top of the material they're measuring. This technology works well with highly reflective liquids such as water, but poorly reflective matter such as polyethylene has a low dK, and it doesn't always provide a strong enough return signal to calculate a level measurement accurately. In the past, if a liquid's dielectric constant was too low, radar might not be sensitive enough to measure it. That's changed because of advancements in dynamic range.

MOUNTING FLEXIBILITY
Figure 3: The range of smaller process connections enables mounting in places and in ways never seen before.

Measured in decibels (dB), dynamic range is an indicator of sensitivity. Sensors with a large dynamic range are sensitive enough to register weak signals as well as strong ones. Radar sensitivity varies from manufacturer to manufacturer and even from sen-sor to sensor. The VEGAPULS 64 has a dynamic range of 120 dB, large enough to measure any liquid regardless of dK value.

DIFFICULT MEASUREMENTS IN A DIFFICULT PLACE

An auto parts manufacturer responsible for making vehicle interiors, steering wheels, exterior moldings and trim pieces for a number of large auto manufacturers across the United States wasn't tracking the level in 30 polyethylene tanks — a product with poor reflective properties. Operators were left guessing the level for all 30 tanks, which led to inefficiencies and occasional overflows.

The tanks in this process are very small — roughly five feet tall and a couple of feet in diameter. On top of the tanks is a single 1-in. process connection, and it's pushed to the sidewall because of a bulky mixer mounted on top. To make matters more complicated, there's little to no headspace above the vessel to install a sensor.

All of these factors — poorly reflective medium and a small process connection in a cramped space next to a sidewall — presented a uniquely challenging measurement that wouldn't have been possible in the past. Fortunately, an 80-GHz radar has the sensitivity and the focus needed to make the level measurement (Figure 3).

To install the new instrumentation, technicians had to overcome a few more obstacles. First, they needed a way to bypass the large mixer flange on top of the tank. To do this, they installed an 8-in. extension, which reduced the 1-in. threaded process connection to a ¾-in. thread. Fortunately, this ¾-in. connection wasn't a problem because of the radar instrument's versatile process connections. The new measurements solution en-abled the plant to run its process at an optimal production rate and significantly reduced its risk of overflowing the tanks.

FOCUS, VERSATILITY AND SENSITIVITY

Level measurements that previously were problematic or impossible no longer are an issue as 80-GHz radar becomes the standard. A higher frequency radar provides a tight focus, allowing level measurements to be made in the smallest of spaces. This same technology opens up the availability for a wider range of process connections.

The most common process connection sizes still are available, but now openings as small as ¾ in. can accommodate a radar sensor. With a higher frequency comes a higher sensitivity, too. A dynamic range of 120 dB ensures products with low reflective properties still can get an accurate return signal. The new standard in radar is opening up a new set of possibilities in level measurement. ●

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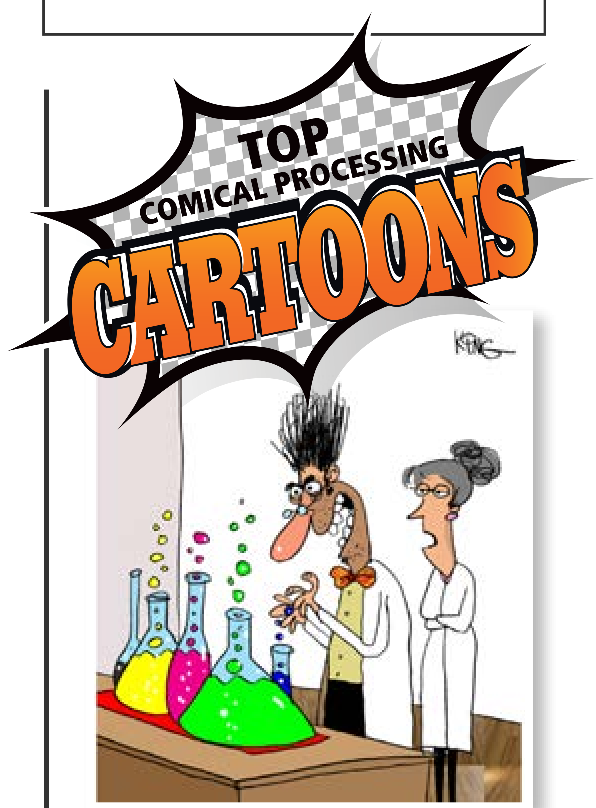

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