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Select the Right Liquid Level Sensor

It's important to consider a variety of factors when choosing the type of technology

By John E. Edwards, P & I Design

LEVEL MEASUREMENT, which is the detection of the phase split between vapor/liquid, liquid/liquid, vapor/solid and even liquid/solid, is a key parameter in the operation and control of modern industrial processes. A reliable outcome depends on the phase conditions being relatively consistent under all process conditions. Unfortunately, the importance of level control isn't always appreciated (see "Don't Underestimate Overfilling's Risks," www.ChemicalProcessing.com/articles/2010/143.html). Failure to measure level reliably has resulted in some of the most serious industrial accidents, including those at the Buncefield, U.K., fuel storage depot and BP's Texas City refinery.

The technologies to measure and transmit process level have evolved significantly since the 1960s. Impulse lines, used to connect instruments to the process, appear less frequently on new installations and are being replaced on existing ones. (Where used, they require specialist knowledge during design, installation and maintenance for reliable measurement.)

Today, sensor developments coupled with data transmission innovation offer reduced installation costs, simplified maintenance and enhanced plant performance.

DATA DELIVERY

Transmission technology development has allowed universal application of self-powered two-wire 4–20 mA dc signals. In addition, SMART transmitters provide bidirectional digital communication and diagnostics capability via the HART (Highway Addressable Remote Transducer) protocol. The 4–20 mA and HART digital signals share the same wiring, offering a centralized capability to configure, calibrate, characterize and diagnose devices in real time, together with reporting capability. Data can be captured from multi-parameter devices without additional hardware, providing predictive maintenance capability.

Meanwhile, development in fieldbus digital communication has enabled field devices to be connected using a single cable bus structure, reducing cabling, installation time and cost. Fieldbus is a device-level network that sacrifices speed for security. Several protocols are available, with Modbus, Profibus PA and Foundation being the most common. (See "Take Advantage of Fieldbus," www.ChemicalProcessing.com/articles/2010/149.html.)

Fieldbus technology is more complex and costly, requiring suppliers to provide sensor options to meet the different standards. Plant layout, sensor interface capabilities and data management infrastructure guide fieldbus selection.

MEASUREMENT TECHNOLOGIES

Here, we'll focus on liquid level measurement because it's usually the key to reliable and safe plant operation. Normally processors hold flows steady and let levels change within limits — this requires

reproducibility. Accuracy is important for tanks used for stock and custody control.

A variety of mechanical and electronic technologies for level measurement are available:

Hydrostatic. This continuous indirect method measures the pressure due to liquid level and density plus over-pressure. The sensor measures the difference between this pressure and a reference one, normally atmospheric; so, it's not well suited for vacuum and pressure service. Instruments come in flanged-mounted or rod-insertion styles, the latter not being recommended for turbulent conditions. Typical accuracies claimed are ±0.2% of reading but this depends on process fluid properties and conditions.

Float displacer. Suitable for point or continuous applications, it measures the change in buoyancy via a torque tube, lever or servo arrangement. The continuous measuring range is set by the displacer length immersed in the tank's external cage, which is preferable for noisy applications, or servo mechanism. The point method uses a float, with the range being limited by the length of the float arm.

Nucleonic. Good for point or continuous duties, this non-contact method, which is independent of fluid density and viscosity, measures the signal strength of a radioactive source beamed across a vessel and has typical ranges of 0.24 m to 3.36 m. Accuracies generally claimed are ±2% of reading. It's the preferred method for monitoring level in flash vessels and reboilers under all temperature and pressure conditions.

Radar. Applicable to point or continuous applications, it measures the travel time of an impulse reflected from the liquid surface. Interference echoes from tank internals, and agitators are suppressed and signals can be characterized to give liquid volume. The sensor doesn't contact the liquid but is exposed to headspace conditions, which don't affect the measurement. Reflectivity requires the liquid dielectric constant, ε_R, to be at least 1.4 (hydrocarbons are 1.9–4.0, organic solvents

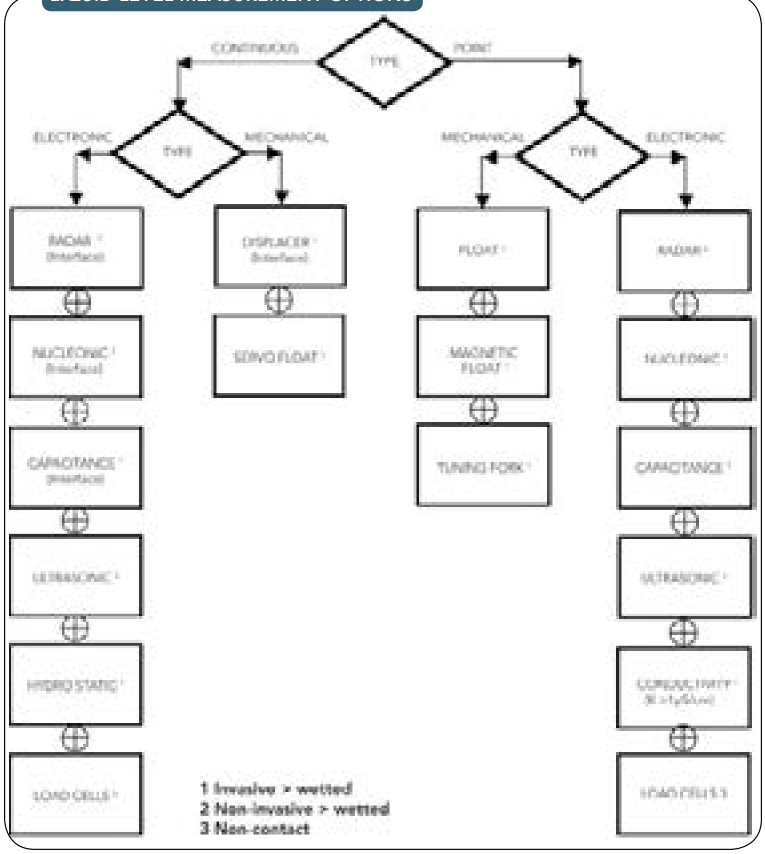

Figure 1. A variety of electronic and mechanical methods are available.

are 4.0–10 and conductive liquids are over 10). Adjusting the antenna and signal conditions allows tailoring to the particular process, with guided radar used for low ε_R and turbulent conditions. The method can handle custody transfer because of its claimed accuracy of ±0.5mm.

Capacitance. For point or continuous service, it suits liquids that can act as dielectrics. Sensitivity increases with the difference in dielectric constants, $\delta\varepsilon_R$, between the liquid and the vapor space or between the two liquids. Special designs, involving coated and twin probes, are used when $\delta\varepsilon_R$ is under

1.0, conductivities exceed 100 µmho, or to overcome probe build-up effects, and when vessel material is non-conducting. Typical accuracies claimed are ±0.25% of span. However, fluid properties affect measurements, so the method isn't suitable for changing conditions. Maximum conditions are 200°C at 100 bar and 400°C at 10 bar.

Ultrasonic. Suitable for point or continuous use, it is based on the time-of-flight principle. A sensor emits and detects ultrasonic pulses that are reflected from the surface of the liquid. The method is non-invasive, with some types being non-contact, and isn't affected by ε_R, conductivity, density or humidity. Maximum conditions are 150°C at 4 bar.

Load cells. Appropriate for point and continuous applications, such devices, which can be based on strain gauge or piezoelectric technology, measure the weight of the process vessel plus contents. Individual load cell accuracy of 0.03% of full scale is achievable but overall performance depends on correct installation practices to exclude external forces due to associated piping and equipment. For vessels with jackets, agitation and complex piping, it's difficult to obtain an acceptable accuracy. When the container can be totally isolated, as in final dispensing and filling applications, precision weighing can be achieved.

Tuning fork. This method can detect point liquid level but isn't suitable for viscous and fouling applications. Maximum conditions are 280°C at 100 bar.

Conductivity. Good for finding point level, it requires a liquid conductivity exceeding 0.1 µmho and frequently is used on utility and effluent pump control systems.

Figure 1 summarizes the nature and applicability of these measurement technologies. Figure 2 gives more details on their use for continuous measurements. Impulse line applications have not been considered for main process applications but can still find use on general services and less critical installations.

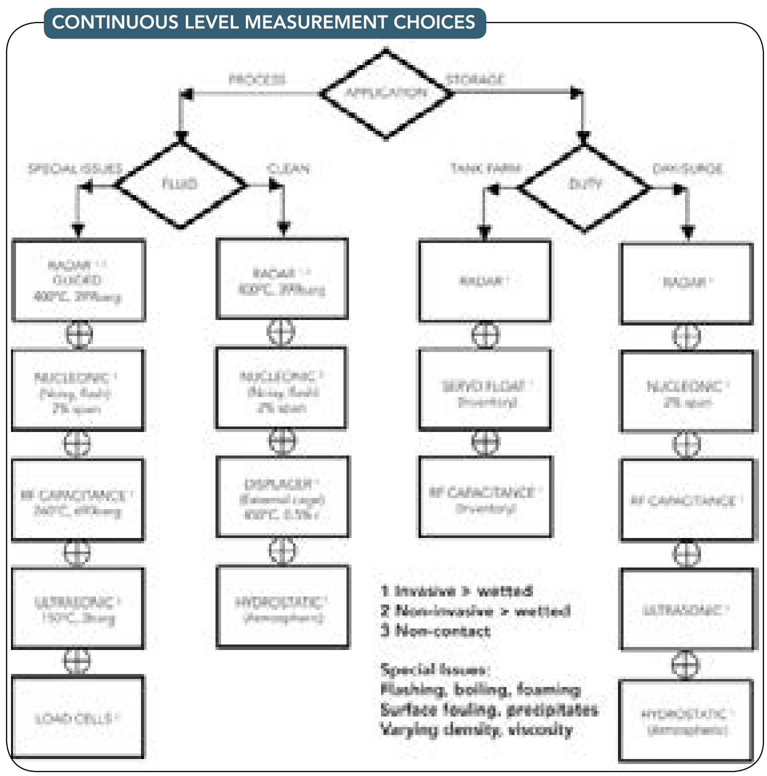

Figure 2. The nature of both the service and the fluid affect the selection.

Of course, besides technical suitability, it's important to consider economics. Typical comparative costs, from lowest to highest, are: conductivity → capacitance → tuning fork → hydrostatic → displacer → ultrasonic → load cell → radar → nucleonic.

APPLICATION CONSIDERATIONS

Selection also must consider both the process and its control.

Process. It's essential to understand the physical property variations of the process fluids and the phase changes that may occur within the process during normal and abnormal conditions.

Boilers, flash vessels and distillation column bottoms involve boiling liquids, resulting in noisy

levels. Displacers in external cages frequently are used on steam generators and flash vessels, provided the process fluids are of low viscosity and relatively clean. The non-contact nucleonic method will prove most reliable for distillation column bottoms, where reproducibility is more important than absolute accuracy. While expensive, it can be more than justified given its value in providing stable column operation and in preventing reboiler fouling due to loss of level.

Avoid the use of impulse lines in level systems if the process pressure varies and there's a tendency for solids' formation due to freezing, precipitation or polymerization. Purging the lines with inert gas or process compatible fluids will have limited success and is high maintenance.

Nucleonic level detection provides a powerful tool to perform on-line process diagnostics. Typical applications include monitoring level profiles in tray towers, distribution in packed beds, locating level build-up and blockages in vessels, and general flow studies.

Control. Let's consider a general equation describing the output, m, from a three-mode (proportional-integral-derivative) controller:

$$m = (100/P)[e + (1/T_i)\int e\,dt + T_d\,(de/dt)] + m_o$$

where P is proportional band, %; T_i is integral action time, min.; T_d is derivative action time, min.; m_o is steady-state controller output; and e is $\pm(X_{set} - X_{meas})$, the error between set point and process measurement.

Based on its form, we can predict the following behavior:

1. If there's no error the controller output will equal steady-state output, mo.

2. Controller gain is $100/P$. So, increasing P decreases the controller gain with % change of output for same % error change reducing and vice versa.

3. The integral term, $1/T_i$, indicates that as T_i rises its effect falls. An increase in error results in an increase in rate of change of controller output. Slow processes can use higher T_i, provided the process isn't too slow to absorb the energy change — if it is, cycling will result.

4. Decreasing the derivative term, T_d, reduces its effect. Increasing error rate change increases % controller output change. In typical continuous process applications liquid level measurements are noisy; they present rapid changes in error with time, i.e., large de/dt. So, derivative mode never should be used — otherwise equipment damage may occur.

Continuous process applications often rely on surge vessels to minimize flow upsets to downstream units. The level is allowed to float between minimum and maximum values. Use proportional control mode alone with flow cutback override control.

Controlling level at a fixed point, such as for distillation column bottoms, requires proportional and integral control modes.

High integrity protection. For a level measurement deemed critical for plant safety it's common practice to install two or more redundant level systems. Redundancy implies elimination of the likelihood of a common mode failure, which can result when using identical methods, instrumentation and manufacturer.

Inherent in high integrity protection is the principle of fail-safe design. However, the total system needs in-depth study to determine the potential of fail-to-danger scenarios and to ensure testing facilities and procedures are acceptable.

Frequency of testing for satisfactory operation can dramatically impact system reliability. Unfortunately, conducting real on-line testing of level instrumentation generally is rarely possible because creating the process condition required, for instance, high level in a vessel, usually isn't feasible. ●

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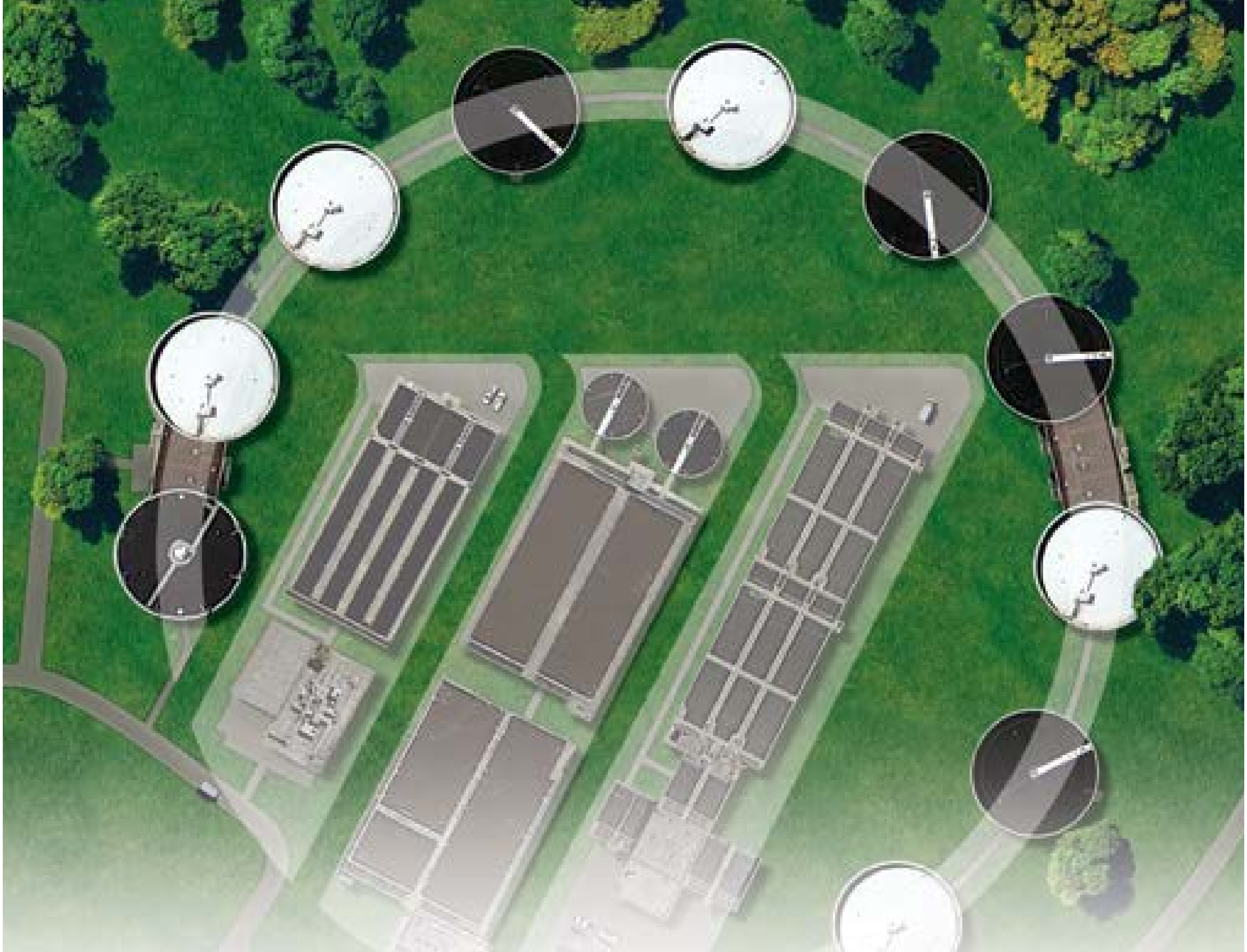

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Properly Measure Liquid/Liquid Interfaces

Follow a simple rule for location of level gauge nozzles

By Jonathan Webber, Fluor Canada, and Patrick Richards, Irving Oil

DETAILED DESIGN of a vessel includes determining the proper locations for level gauge/transmitter nozzles. There's little debate on the correct nozzle locations for vapor/liquid interface level measurements — it's well understood to locate the upper nozzle in the vapor space and the bottom nozzle in the liquid phase. Martyn (1) discusses the challenges of liquid/liquid interface level measurements when using bridled (externally mounted) configurations. Our experience indicates that much confusion exists about the correct nozzle configurations for level measurements of liquid/liquid interfaces. Common questions include: "How do we know that the interface level in the gauge will be the same as the vessel?" and "Won't the light liquid get trapped on top of the heavy liquid in the gauge?"

So, here, we'll provide a simple "Golden Rule" for nozzle placement that we have used successfully in numerous refinery interface measurement applications.

THE GOLDEN RULE

For proper location of externally mounted level-measurement nozzles, ensure that at least one nozzle is located in the top liquid phase and at least one nozzle is located in the bottom liquid phase.

If this simple stipulation is satisfied and the top and bottom fluids are immiscible and have different densities, then we can be sure, at equilibrium, that the pressure balance will equalize the interface levels in the gauge and the vessel.

Either a non-flooded (i.e., top nozzle connected

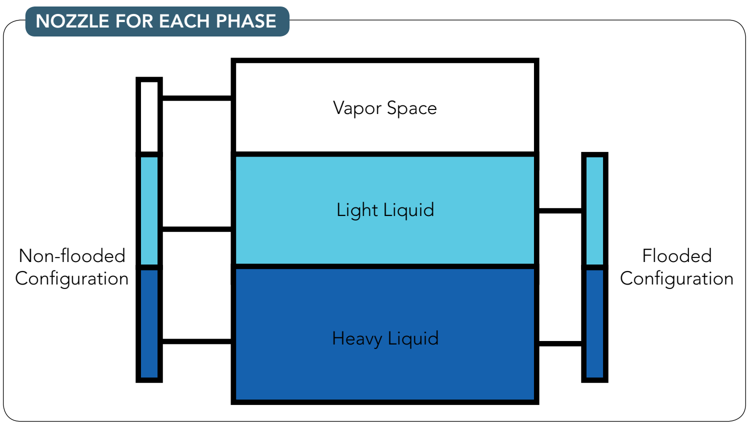

Figure 1. This arrangement satisfies the Golden Rule and ensures the same interface level in the vessel and gauge.

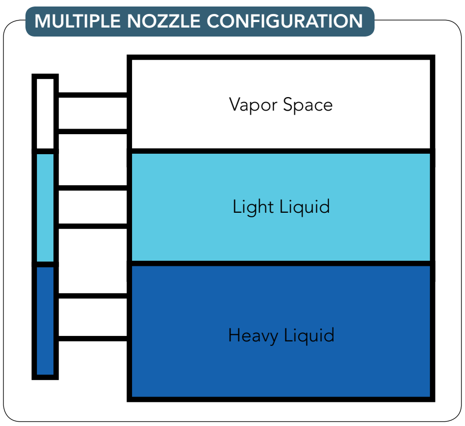

Figure 2. At least one nozzle must be connected to each liquid phase to comply with the Golden Rule.

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to vapor space) or flooded configuration will allow the pressure balance to equalize the interface levels in the drum and the gauge (Figure 1). The non-flooded configuration offers the advantage of allowing for a total liquid level measurement. Sometimes multiple nozzles are used to cover the expected range of liquid inventories. In these cases the Golden Rule is satisfied as long as at least one nozzle is connected to each liquid phase at all operating conditions (Figure 2).

Oil/water interfaces are common in refining, and we often hear the question: "Isn't it possible for the pressures to balance in such a way that the height of the interface in the gauge isn't the same as the height of the interface in the vessel?" A common argument is that the extra head of water in the gauge will compensate for the smaller head of oil in the gauge, thereby allowing the equilibrium interface level in the gauge and vessel to differ (Figure 3). This argument is flawed — if the Golden Rule is followed, the two levels will equalize. The sidebar provides a simple mathematical proof by contradiction.

APPLYING THE RULE

In practice it can be difficult to locate nozzles to satisfy the Golden Rule under all operating conditions. If a vessel may contain widely varying levels of liquid inventories, then it's worth considering multiple nozzle locations. Select nozzle positioning and spacing to minimize the chance that one no longer is connected to a liquid phase. It's possible for light liquid to become trapped in the gauge, causing an error when the light liquid inventory no longer is connected to a nozzle (Figure 3). This could occur, for example, when the heavy liquid level drops and too large a nozzle spacing was used.

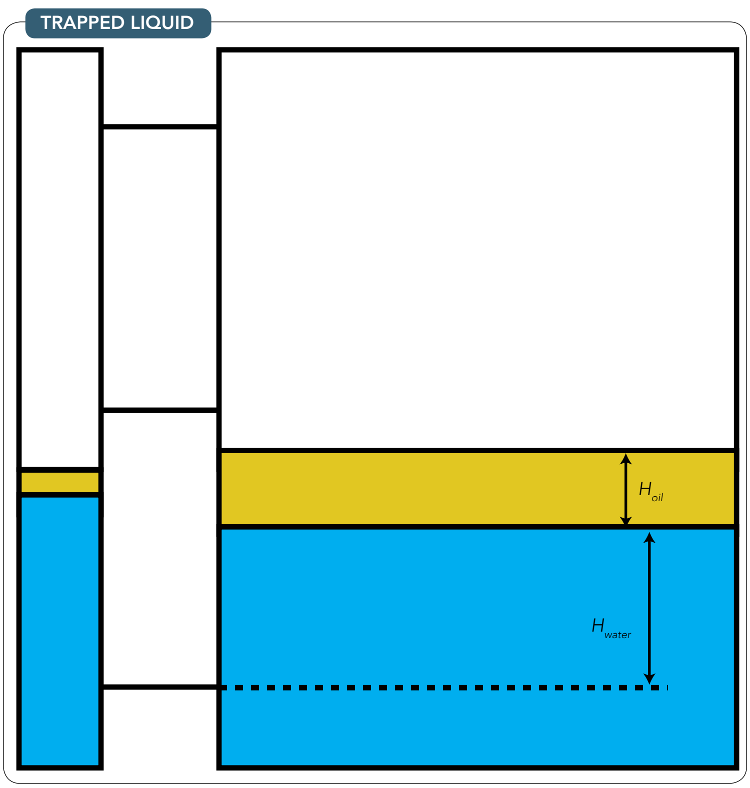

Figure 3. In this case liquid becomes trapped in the gauge.

Considerations other than nozzle locations can affect the accuracy of the level measurement. It's well known that temperature differences between the fluid in the gauge and the vessel can lead to erroneous readings.

TEST THE RULE

In Figure 4 assume the Golden Rule is satisfied — i.e., each liquid phase in the vessel is connected to the gauge by a nozzle. At equilibrium the pressures at the middle and bottom nozzles are balanced via Eqs.1 and 2, respectively:

$$P_v + \rho_{oil}\, g\, H_1 + \rho_{water}\, g\, H_2 = P_v + \rho_{oil}\, g\, H_1^* \quad (1)$$

$$P_v + \rho_{oil}\, g\, H_1 + \rho_{water}\, g\, (H_2 + H_{tap}) = P_v + \rho_{oil}\, g\, (H_1^* + H_2^*) + \rho_{water}\, g\, H_{water} \quad (2)$$

where P_v is the vessel vapor pressure, ρ_{oil} is the oil density, ρ_{water} is the water density, and g is gravitational acceleration. Substitution and algebraic rearrangement yields:

$$\rho_{oil}\, H_2^* = \rho_{water}\, H_2^* \quad (3)$$

Because the densities of the oil and water phases aren't equal and $H_2^* \neq 0$ (remember we assumed that the Golden Rule is satisfied), then Equation 3 is a contradiction and can't be true. Therefore, the equalization shown in Figure 4 isn't possible. You can examine different equalizations, all of which will result in contradictions unless the gauge interface and vessel interface levels are equal.

DISPROVING EQUATION 3

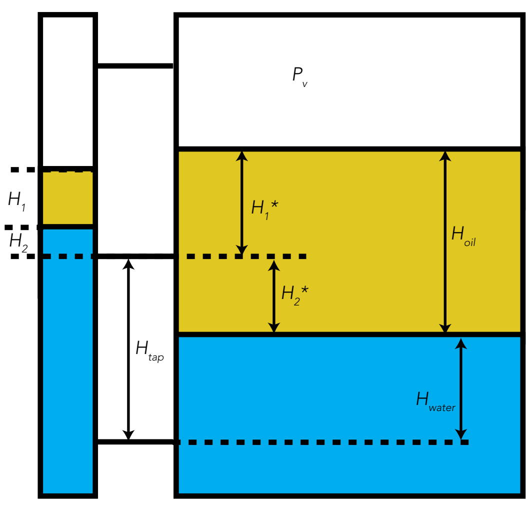

Figure 4. If the Golden Rule isn't satisfied, equalization shown isn't possible.

AVOID ERRORS

Adhering to our simple Golden Rule will ensure the liquid/liquid interface in the gauge matches the interface level in the vessel. If you can't manage liquid inventories to satisfy the rule then errors may arise in the measurement.

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Improve Reactor Vessel Measurement

Non-contact radar level meter speeds production and boosts worker safety

A NORTH Carolina-based specialty chemical manufacturer, a major producer of insect repellent, was looking for a better way to measure the liquid level in its glass-lined agitated reactor. The company uses a number of complex technologies to manufacture sebacates, adipates, isophthalates, catalysts, alkyds, and other natural and renewable chemistries based on castor and citrates.

The chemical manufacturer always had relied on the low-tech "inch count" method, in which an operator inserts a tape measure into the hatch and measures down to the liquid level to calculate how many gallons are in the reactor.

The information is used to calculate the "drying rate" to predict when the process is finished and the product is ready for post-processing. Operators look at starting and ending gallons to calculate the percentage of moisture, which is important for product quality. If they start at a certain inch level and apply heat to the vessel, they measure how fast it's dropping to determine how many gallons have dried.

The manual inch count also is used to "charge the heel," which refers to dispensing starting chemicals for the next batch. Based on the amount of heel material in the reactor, operators can calculate how much moisture and other chemicals must be added for the next batch.

The information is critical to the manufacturing process and inch counts may be taken as many as 10 times a day. However, before taking a manual inch count, operators must stop the reactor and wait for the contents to cool, resulting in a great deal of lost production time.

THE SEARCH FOR AN EASIER PROCESS

The company's engineering manager, Todd Yarborough, went looking for a less time-consuming method of getting the vital information. He also was seeking a way to minimize worker exposure to chemical vapors used in the production process.

The engineer sought out Krohne, a manufacturer of measuring instruments for the process industries, because he had experience with their equipment at another chemical facility.

Michael Barber, Krohne's Southeast district sales manager, recommended the Optiwave 7300C, a non-contact frequency-modulated continuous-wave (FMCW) radar level meter. According to Barber, "The Optiwave 7300C model is designed for distance, level, volume, and mass measurement of liquids, pastes and slurries. It gives a more stable measurement than pulse radar and is well suited to agitated process conditions. It can operate at very low and very high process temperatures as long as the process connection temperature limits are observed."

After conducting a two-week trial demonstration, Yarborough purchased the Optiwave 7300. Installation and set-up of the meter only required fitting the gauge to the tank, wiring it and turning it on.

"Krohne configured the unit in 10 minutes and the device immediately began continuously measuring how many inches and gallons were in the vessel without stopping production or operator interaction," Yarborough said. "We got immediate feedback from operators that they loved it, because it enabled them to perform their duties without opening the hatch. In

addition, using the meter to eliminate the manual inch count reduced our cycle time considerably."

The temperature trend in the reactor was about 105°C for this chemical reaction. Yarborough said that he has seen high ambient temperatures and huge temperature swings and the device still functions, not getting lost in the vapors.

LOW DIELECTRIC CHALLENGE

According to Yarborough, one of the challenges of finding the right level measurement device was that the material's dielectric is very low, less than 2. Such low dielectric provides weak reflection and can be difficult to measure with microwave energy, so he was concerned whether the device could maintain a strong signal. The equipment demonstration proved that the device could track levels even with the low dielectric.

The Krohne meter offers a maximum measuring range of 131 ft (40 m). This enables it to operate with a larger bandwidth, ensuring sharper resolution and resulting in measurements that are more accurate as well as repeatable. "The higher signal dynamics of the Optiwave 7300 C allow the detection of the smallest level changes and clearer location of the product's true surface," Barber said. "In addition, objects such as struts, inlets, and ladders, and even agitated surface or foam, have little effect on signal strength."

The meter offers long antenna versions that can be extended to suit different nozzle lengths. It can be equipped with a drop antenna for corrosive liquids (with optional PTFE/PP flange plate) or where product build-up is likely to occur. A sealed drop antenna extension option is available for pressurized tanks.

According to Barber, "In this application, we used the smallest antenna we have, 1.5 inches, in order to facilitate the installation. However, the smaller the antenna the larger the beam angle — resulting in wide dispersion of the signal over distance. Signal intensity is the weakest with this antenna, which does add to the measurement challenge, yet this is overcome by the tremendous signal processing of the Optiwave electronics."

The company started with three of the level meters and intends to gradually install them on all its remaining reactors. "The physical size works well with our operations," said Yarborough. "Also, the required antenna was an easy installation for us, because the existing nozzle and antenna size fit into an existing nozzle on the reactor. Actually, one reason we went to higher frequency radar was to make it compatible with the existing nozzle. Another nice feature is that I have all our instrument configurations on file, so it will be easy to connect new instruments and download configurations as they come on line."

NON-CONTACT RADAR SPEEDS PROCESS

Figure 1. This continuous non-contact radar level meter eliminates the need for operators to conduct multiple manual inch counts each day, reducing cycle times and worker exposure to chemical vapors.

KROHNE, INC., Peabody, Mass., is a manufacturer and supplier of industrial process instrumentation. For more information, visit http://us.krohne.com.

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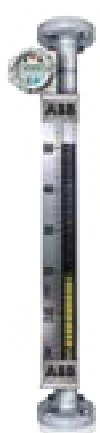

The KM26 Magnetic Level Gauge and the AT200 Magnetostrictive Level Transmitter provide continuous measurement and transmission of an analog and/or digital signal of interface levels in different types of separators. Interface applications in the oil and gas industry are some of the most challenging level detection processes. The magnetic field of the K-TEK Magnetic Level Gauge's custom engineered float provides a reliable total and/or interface output signal, even when thick emulsion is present. Learn more about why ABB Level Measurement is your solution for the oil and gas industry. **www.abb.com/level**

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