TANK GAUGING SYSTEMS USED FOR BULK STORAGE OF GASOLINE†

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This paper presents an outline of the most commonly adopted tank gauging and level measurement systems used in the gasoline storage industry. It highlights the advantages and disadvantages of the named systems and gives a brief explanation of how the systems work.

The outcome of discussion held with professionals and manufacturers in the industry and their view on how level measurement technology is evolving and improving is then summarized showing how more accurate and operationally reliable level measurements should be possible in the future.

KEYWORDS: Level measurement, tank gauging, Buncefield, gasoline storage

INTRODUCTION

A major contributor to the Buncefield fuel storage facility explosion of December 2005 has been determined to be the failure of the level measurement system on tank 912 and its failure to operate according to expectations[11]. Following the prosecution surrounding this incident, two major control systems companies, amongst others, were prosecuted and convicted of health and safety breaches that contributed to the incident.

This paper presents an outline of the most commonly adopted tank gauging and level measurement systems used in the gasoline storage industry. It is intended that this review will present information to help reduce the risk of such an equipment failure contributing to a tank overfill event in the future, by highlighting appropriate and established level measurement systems for gasoline storage facilities.

EXISTING TECHNOLOGY

There are numerous methods used to measure fuel levels within storage tanks in the fuel storage industry. All of those stated below have advantages as well as shortcomings, but none the less all are reputable level measurement systems in use in the industry.

The most commonly used level measurement technologies are:

- Dip tape level measurement
- Float operated, wire guided, inductively coupled systems
- Servo-operated float systems
- Radiation backscatter (non invasive)
- Radar tank gauges
- Hydrostatic tank gauges (HTGs)
- Ultrasonic tank gauging
- Air bubbler level measurement
- Thermal Differential Monitoring

DIP TAPE LEVEL MEASUREMENT

A dip tape is a manual user operated measurement device, which consists normally of some form of calibrated tape with a weight attached to the end. The units of measurement can be metres, feet or yards. The weight (a bob) is lowered into the tank manually by an operator. The weight is continuously lowered into the tank until the operator feels the weight touch the striker plate fixed on the bottom. At that point the grading on the tape is read. The tape is then retracted whilst the operator observes when the retracting tape becomes wet. The grading on the tape is then noted again. The difference between the two recorded values is then noted. From dimensional and capacity information known about the tank, its ullage can be calculated.

The accuracy of the measurement using this method can vary significantly depending upon operator skill and experience. In addition, accuracy of dipping measurements can be adversely affected by high winds and cold temperatures.

Safety regulations in place on many fuel storage sites prevent operators from being present on fuel storage tanks,[10] therefore preventing the use of this method on some sites.

The dip tape is a quick level measurement method but should only be used as a means of double checking measurements made by other, probably automated, means. It should not be a fuel storage site's only means of determining tank levels.

Dip tapes are the traditional method of tank content measurement. However, newer technologies have taken over which rely far less on operators and their inherent potential for introducing measurement error. Accuracy and consistency is highly dependent on the operator.

There have been reported cases where a dip tape weight has worn a hole into the bottom of a tank because of the absence of a striker plate. In such cases the loss of a considerable quantity of fuel is possible.[9]

FLOAT OPERATED, WIRE GUIDED, INDUCTIVELY COUPLED SYSTEMS

A wire is fixed at both the top and bottom of the tank, as shown in Figure 1, and is used as a guide for the float. The float contains an inductively coupled transducer, to which the wire provides power. At short intervals the primary coupling is interrupted, and a secondary inductive coupling from the transducer to the conductor, on the wire, is achieved. Measurement is achieved by conductors located at known intervals on the wire.

This is a widely used level measurement method. However its perceived accuracy is not considered to be good enough for either custody transfer or stock accounting.

Material build-up can hinder free movement of the float, therefore it cannot be used in so-called dirty applications. Even in clean applications, such as gasoline level measurement, it is possible for the float mechanism to jam.[2]

Components of float operated wire guided systems are prone to accelerated wear because of continuous movement of the drive mechanism attached to the float on the liquid surface. Therefore, the level of reliability these systems offer can potentially be poor. Due to the varying levels of reliability, accuracy of measurement and the method's high maintenance demands the fuel storage industry are moving away from using this type of system in favour of non-invasive measurement approaches.[10]

SERVO-OPERATED FLOAT SYSTEMS

The servo-operated float system, as illustrated in Figure 2, utilises the displacement of liquid contained within the tank for continual measurement. The retractor servo gauge is used to move a float that is continually measuring the liquid in the tank. This is done by driving the float through the tanks open space until it makes contact with the liquid surface level. As the level changes, the system always aims to maintain the float in equilibrium, which produces the level measurement.

Magnetic floats are generally used in continuous float type level detectors. Of these floats the greatest measurement accuracy is achieved with magnetostrictive technology. This method is considered more accurate than float operated wire guided systems and plumb-bob gauges because the retractor reduces the potential for tape hang-ups by keeping the tape taut. Magnetic disc float level detectors are favoured as a very accurate device for liquid level measurement. This type of level measuring system is normally intrinsically safe and measures continuously.

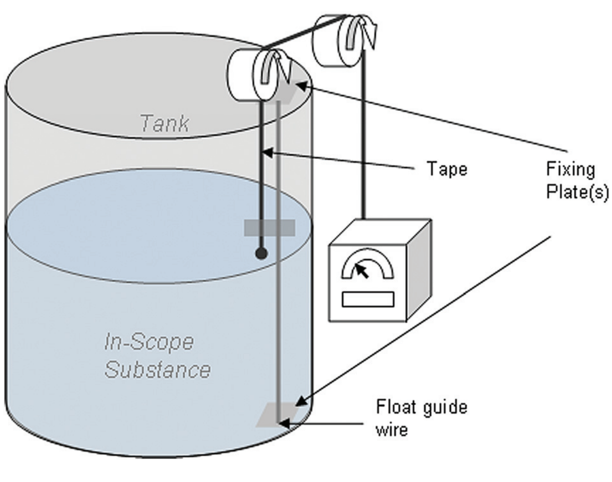

Figure 1. A float type level measurement system

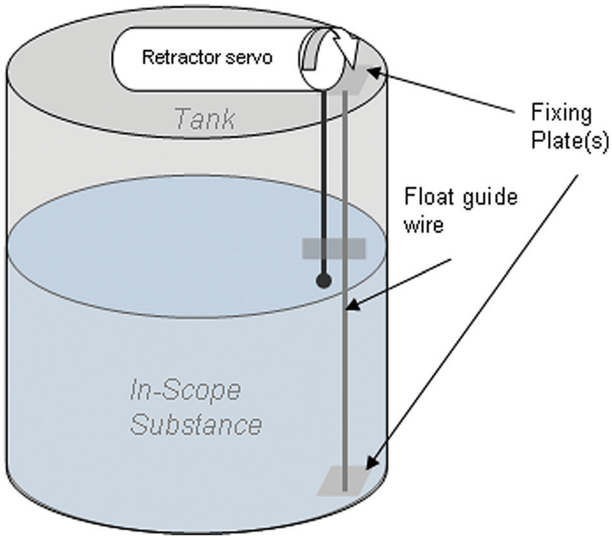

Figure 2. A servo-operated float type level measurement system

Servo-operated float systems can be an accurate means of level measurement provided that the system is well maintained. Reliability of this method is heavily dependant on maintenance because this instrument uses many moving parts, which are critical to its accurate operation. Therefore, ensuring a reliable level measurement consistently, this type of system requires a high level of maintenance and cleaning to ensure the tank contents do not penetrate the system instruments.

This method of level measurement is approved by a number of European governments and agencies for custody transfer applications because of the measurement accuracy that can be achieved.

RADIATION BACKSCATTER (NON INVASIVE)

This method of level measurement utilises a radioactive source as a transmitter and a radiation detector to determine the level of material within the containing vessel. Figure 3 shows diagrammatically a radiation level measurement system setup.

This type of system is generally very expensive to purchase, install and maintain when compared to float type systems. Additionally, due to the radioactive sources used, these systems will require licensing in many instances.

The costs and licensing requirements of this type of system mean that currently it is very rarely used in the fuel storage industry. The accuracy and non invasive

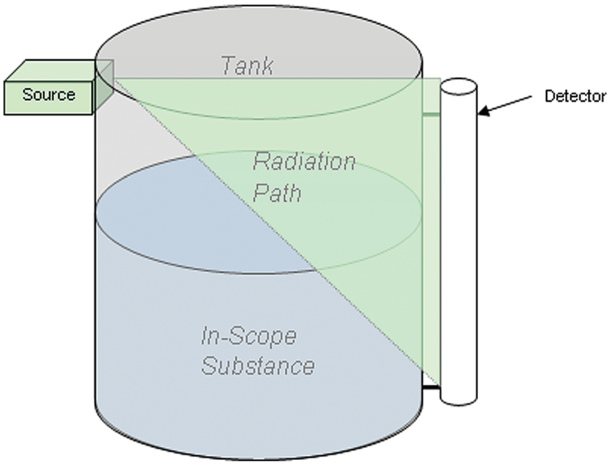

Figure 3. A radiation level measurement system.

nature of the method are generally thought to be far outweighed by the high cost.

RADAR TANK GAUGES

Radar tank gauging was originally developed for use on crude oil carriers because there was a requirement to be able to measure the quantity of oil by non-invasive means.[10] Figure 4 shows diagrammatically a simple radar level measurement system.

This method uses a probe, known as a 'waveguide', situated in a container delving below the liquid surface. The waveguide is used to perform the measurement by transmitting a periodic pulse from below the surface, which is then received in an attenuated form by a receiver somewhere within the tank but not in contact with the liquid. There are a number of different receiving methods that are used to detect the reflected signals. Those currently used and accepted are:

(1) Time Domain Reflectometry (TDR).
(2) Newer higher efficiency low power, DC sensing methods are also available. These are:
   - Guided Wave Radar (GWR). Based upon TDR.

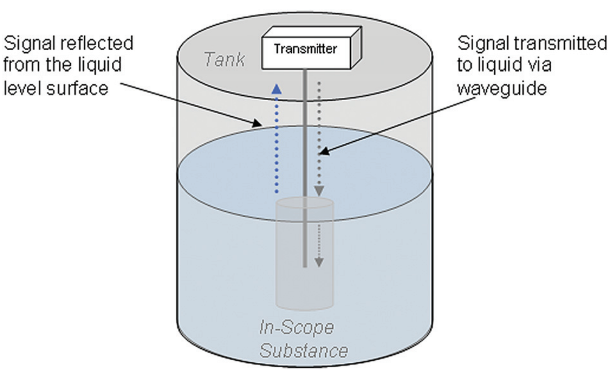

Figure 4. A radar level measurement system

   - Phase Difference Sensor (PDS). Determines level from change in phase angle of material in container. This method can only accurately provide level measurements in materials with dielectric values greater than 1.4 (i.e. this will not work well with water based materials).

This method of level measurement has been shown to measure erroneously up to 10 mm/m in the presence of gasoline[6]. Radar level measurement used with heavy hydrocarbon materials does not experience errors of this magnitude assuming it is designed and set up correctly for the application.

HYDROSTATIC TANK GAUGES (HTGs)[2]

Hydrostatic Tank Gauging (HTG) is a continuous monitoring system and works by placing two pressure sensors a known distance apart in the tank, then measuring the temperature at a point between these two sensors. The pressure readings are then used to calculate the mass of material in the tank using the series of simplified equations below:

Simplified density of liquid (D)

$$D = \frac{P1 - P2}{H} \tag{1}$$

where:

$P1$ = Pressure at sensor $P1$ in bar
$P2$ = Pressure at sensor $P2$ in bar
H = Distance between $P1$ and $P2$ in metres

Standard Density at 15.5°C (60°F) ($Dref$)

$$Dref = f(D, T) \tag{2}$$

Simplified Standard Volume (SV)

$$SV = \frac{M}{Dref} \tag{3}$$

Where M is simplified mass (see equation (6))

Simplified Level (L)

$$L = \frac{P1}{D} \tag{4}$$

Effective Tank Area (A)

$$A = \frac{V}{L} \tag{5}$$

Simplified Mass (M)

$$M = P1 \times A \tag{6}$$

Figure 5 shows a simple diagram to illustrate a HTG level measurement system setup.

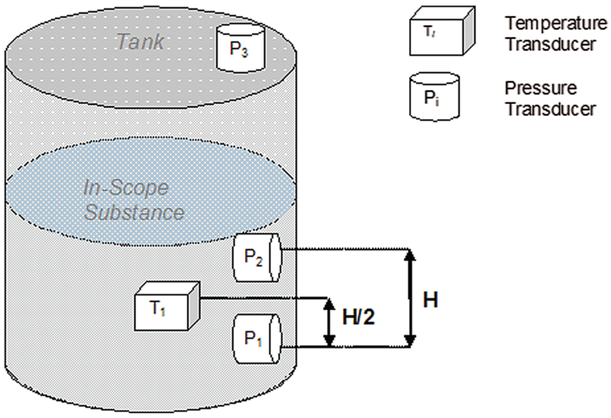

Figure 5. A hydrostatic tank gauging level measurement system

Hydrostatic tank compensation (HTC) can be implemented using one pressure difference sensor, which compensates for measurement errors, which can be introduced when using two individual sensors.

This type of level measurement system is well regarded in the fuel storage industry because it has no moving parts, can be implemented using commercially available components and technology, and is highly accurate. It can be used for level measurement of the following types of material:

(1) Clean liquid measurement (atmospheric & pressurised)
(2) Hard to handle fluid measurement (atmospheric & pressurised)
(3) Bi-phase material
(4) Cryogenic material
(5) Boiling material

HTG is popular because this type of system has no moving parts within the tank. A reasonably accurate level measurement can be obtained because measurement is based upon volume to provide a quantity in terms of mass. This in turn provides a means of leak detection. However the accuracy of the measurement is highly dependant upon well maintained and calibrated pressure sensors. Additionally accuracy of the measurement drops if the material being measured stratifies because of temperature or density. Therefore the measurement of boiling materials or bi-phase materials will be less accurate with an HTG system.[6]

A potential problem with HTG systems is that placement of sensors can lead to error introduction that may lead to inaccurate level measurement. To achieve high accuracy measurements the pressure sensors used must be at least 20 to 30 times better (higher quality) than those used in standard process control applications.

Another drawback of the HTG approach to level measurement is that if a measurement is taken where the level of the liquid is below the height of the higher pressure sensor, an unreliable level and density measurement can be given. Therefore, the greatest accuracy in using this type of system is only achievable in a limited portion of the tank, namely in and around the vicinity of the pressure sensors.[7]

The accuracy of measurement using this type of system can be reduced if the sensors used become coated or poisoned through prolonged exposure to the fuel substance contained within the tank. Routine maintenance and component replacement should however minimise this issue.

ULTRASONIC TANK GAUGING

Ultrasonic level sensing is a non-contacting level measurement method. The sensors emit acoustic frequency waves in the range of 20 kHz to 200 kHz that are reflected back from the liquid surface and detected by the emitting transducer.

Ultrasonic level sensors detect change of speed of sound. The speed of sound will change because of factors such as moisture, temperature, and pressure. To overcome this correction factors are applied to the level measurement to improve measurement accuracy.

Mounting and positioning of the ultrasonic transducer can have a significant impact upon accuracy therefore careful design and planning is required to ensure optimum response to the reflected ultrasound transmission. Additionally to maximise measurement accuracy the tank should be relatively free of unnecessary brackets and ladders because they act as obstacles to the ultrasound signals and may cause return signals to be inaccurately received.

A widely recorded shortcoming of ultrasonic tank gauging systems is that they are susceptible to ringing. This occurs when the transmitted signal is reflected back to the transducer from an unintended surface, namely a surface other than that of the liquid in the tank. Ringing can be compensated for and in a lot of cases minimised so that it has negligible impact on measurement accuracy.

An additional shortcoming is that it has been widely accepted throughout industry that non-contacting ultrasonic devices are erroneous when used in vacuumed nitrogen blanketed storage vessels. Accuracy can be improved by having a fixed reference point within the vessel and to instead continuously monitor the changes in level with respect to this fixed point.[3]

This tank level measurement system is relatively cheap when compared to alternative systems that offer comparable accuracy. Figure 6 shows a simple diagram illustrating an ultrasonic level measurement system setup.

AIR BUBBLER LEVEL MEASUREMENT

Air bubbler systems have a tube with an opening below the surface of the liquid level. A fixed rate airflow passes through the tube and out of the opening as shown in Figure 7. In the context of this method air can refer to either air or nitrogen.[1] Pressure in the tube is proportional to the depth (and density) of the liquid over the outlet of the tube. There are no moving parts associated with an air

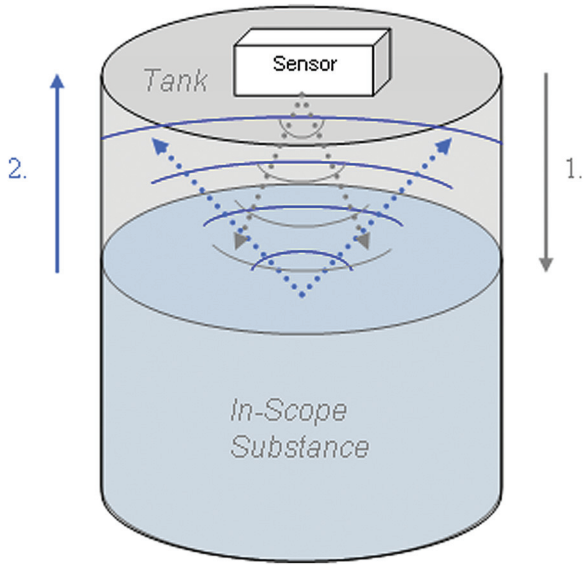

Figure 6. An ultrasonic level measurement system

bubbler, which makes them less maintenance intensive than most other level measurement methods. The only part of the sensor that contacts the liquid is a bubble tube, which is chemically compatible with the material whose level is to be measured.

This method of level measurement is favourable in hazardous areas because there are no electrical components in direct contact with the liquid. The pump or compressor used in providing the stable air supply can be located a distance away in a non-hazardous classified area.

Air bubbler systems are a good choice for open tanks at atmospheric pressure and can be built so that high-pressure air is routed through a bypass valve to dislodge solids that may clog the bubble tube. The technique is inherently "self-cleaning." It is highly recommended for liquid level measurement applications where ultrasonic, float or microwave techniques have proved undependable.

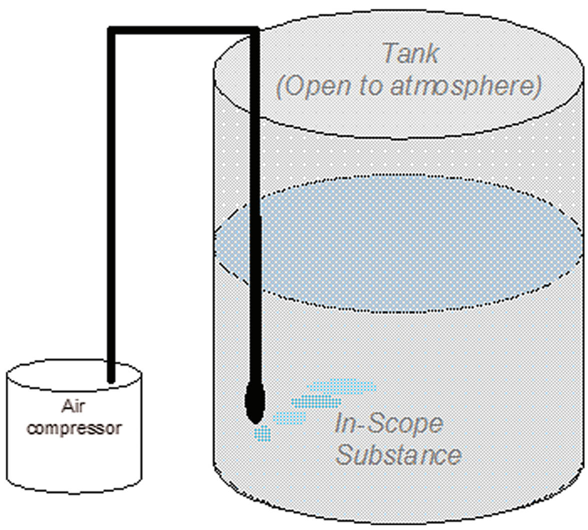

Figure 7. Simple diagram to demonstrate an air bubbler level measurement system

THERMAL DIFFERENTIAL MONITORING

Thermal Differential Monitoring utilizes two Resistance Temperature Detectors (RTD), as shown in Figure 8. One RTD measures the temperature of the fluid around the sensor, the second RTD is self-heated. This provides a temperature differential between the two RTDs. In a liquid level measurement application, the thermal conductivity of the liquid is higher than the gaseous layer above the liquid. When the RTDs make contact with the liquid there is a cooling effect with the liquid absorbing the heat from the heated RTD. This reduces the temperature differential between the two RTDs, and causes the relay to change state. When the liquid level drops below the sensor, the temperature differential increases, causing the relay to reset. This will also work in a liquid–liquid interface when the two liquids have different thermal conductivity such as a tank containing oil and water.[8]

Thermal Differential level measurement equipment can also be used for monitoring the flow of liquid to or from the tank. This method of tank level monitoring has no moving parts. However a two-stage calibration of the monitoring probe is required.

EMERGING TECHNOLOGY

Discussions with system integrators, manufacturers, and consultants who specialise in the field of level measurement and tank gauging in the fuel storage industry are ongoing. These talks establish their views on the level measurement technology currently used in the industry and what evolutionary steps are being taken to improve these technologies.

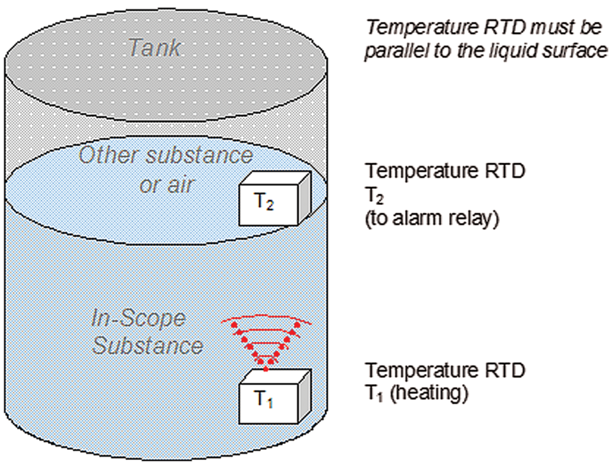

Figure 8. Thermal differential monitoring measurement system

Areas of improvement in next generation level detection systems will include continuous monitoring for error checking and improvements in communications between the level measurement sensor and the alarm annunciator.

An article by Enraf entitled "The Art of Tank Gauging"[10] reported new developments in the tank gauging industry. It is thought that this will be a good indication of the direction this industry is heading towards and what may be uncovered in our further industry consultations set to take place later in this research work.

SERVO GAUGES

The current evolution of this technology uses embedded microcontrollers, which reduce the physical number of electronic components required and therefore the potential for component failure. However, this risk is replaced with that of systematic failure due to software failure in the microcontroller. The software element can also lead to potential difficulties in achieving SIL targets and fulfilling the requirements of BS EN61508[5] and BS EN61511.[4]

There are a number of advantages of the latest generation of servo gauge products. These include, but are not limited to:

(1) Reduced number of moving parts
(2) Reduced operating costs
(3) Mean Time To Failure (MTTF) increased to greater than 10 years (for hardware)
(4) Measurement accuracy increased to within 1 mm
(5) Interfacing capabilities, e.g. communication with other transmitters

RADAR GAUGES

The latest version of this tank gauging technology has the potential of being used for official custody transfer

Table 1. Summary of the pros, cons and applications of the tank gauging systems discussed

Method	Pros	Cons	Applications
Dip Tape	Low cost of measurement equipment	Accuracy is highly dependant upon the skills of the individual performing the measurement	Used in the calibration of newly installed tank gauging systems as well as performing manual level measurements of tank ullage
Float operated, wire guided, inductively coupled systems	Accurate enough for custody transfer	Replacement parts are increasingly difficult to find because manufacturers cease to produce system components	Has been used in the fuel storage industry, but ageing system that fail are being replaced with servo-operated float systems or radar tank gauge systems
Servo-operated float systems	Potentially achieve mm measurement accuracy	• System has mechanical moving parts which will contribute to measurement inaccuracies over time as they wear • Maintenance costs can be high	Favoured in gasoline storage industry
Radiation backscatter	Non-invasive to tank	• Radioactive materials used and may require licensing • High running costs	Not used in gasoline storage industry
Radar tank gauges	• No mechanical moving parts, reducing maintenance costs • Potentially achieve mm measurement accuracy	• Correct initial set up of the radar system is difficult, but is necessary to ensure accurate measurement • Can be prone to "False echo" measurements is tank contains internal fixtures	Favoured in gasoline storage industry
Hydrostatic tank gauging	• Possible to perform density measurements • Low cost purchase and installation	Measurement accuracy is not sufficient for custody transfer	Can be used in gasoline storage, but uncommon in UK
Ultrasonic tank gauging	No mechanical moving parts, reducing maintenance costs	• Not been developed with the fuel storage industry in mind as an end user • Can be prone to "False echo" measurements is tank contains internal fixtures (similarly to radar systems)	Much used in the water industry

because of increased reliability and measurement accuracy of up to 1 mm. Improvement drives for this technology focus on improving antenna design, improvement of diagnostics, and further feature integration such as temperature monitoring. There is also a drive to improve measurement performance when reducing the interaction between the tank and radar signals. The key improvements that the Enraf report highlights for the next generation radar gauges include:

(1) Mean Time To Failure increased to greater than 60 years
(2) Measurement accuracy increased to within 1 mm
(3) Continuous diagnostics
(4) Lower maintenance costs
(5) Enhanced interfacing capabilities. Can communicate with other transmitters using digital communications
(6) Ability to perform density measurements

HYBRID TANK GAUGES (HIMS)

This can be viewed as an "emerging technology" of the tank-gauging world. Hybrid systems are also known as Hybrid Inventory Measurement Systems (HIMS). At the time of writing this technology was still evolving. It stands out from conventional methods because it is able to measure level by conventional automatic tank gauging (ATG) means, volume by pressure sensor and density just like current HTG. Hybrids however, utilise level measurement equipment and a "smart" pressure transmitter and a temperature measurement device, which allows the volume to be calculated more accurately than can be achieved using HTG.[10]

This is the most recent evolution of tank measurement methods and appears to be capable of achieving the greatest accuracy of all present methods because it utilises the most robust elements of existing level measurement technology.

Table 1 summarises each of the level measurement technologies discussed in terms of pros, cons and areas of application.

CONCLUSIONS

It has been concluded that the reliable and accurate measurement of gasoline levels within a tank is not a trivial task. The reliability and accuracy of a number of existing tank level measurement methods and systems are clearly reliant on being correctly set up and correctly maintained. Some methods and systems used in the fuel storage industry currently can have the potential to provide highly accurate level measurement, but at a financial cost.

Evolution in atmospheric fuel storage tank level measurement systems appears to focus upon component reduction by use of software, reduction of mechanical and moving parts and greater emphasis upon self-diagnostics. These developments aim to improve system reliability; potentially extending the manufactures Mean Time To Failure periods by some considerable margin over that of some exiting tank level measurement systems.

Further work is ongoing to investigate developments in tank gauging technology by means of interviews with manufacturers and consultants.

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