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Identification of instrumented level detection and measurement systems used with Buncefield in-scope substances

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Identification of instrumented level detection and measurement systems used with Buncefield in-scope substances

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The Major Incident Investigation Board (MIIB) was formed to investigate the Buncefield incident of December 2005. Its purpose was to make recommendations to help ensure that this kind of incident does not occur again in the future. The MIIB made a number of recommendations associated with the design and operation of Buncefield in-scope fuel storage tanks. This work considers MIIB Recommendations 8 and 13 stated in both 'The Buncefield Incident 11 December 2005, The final report of the Major Incident Investigation Board Volume 2' and in 'Safety and environmental standards for fuel storage sites, Process Safety Leadership Group, Final Report'.

The purpose of this report is to present the current methods and technologies used by industry for implementing tank gauging systems. The report will focus on tank gauging systems and level detection systems that can be implemented for 'in-scope Buncefield substances' storage facilities.

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EXECUTIVE SUMMARY

The Major Incident Investigation Board (MIIB) was formed to investigate the Buncefield incident of December 2005. Its purpose was to make recommendations to help ensure that this kind of incident does not occur again in the future. The MIIB made a number of recommendations associated with the design and operation of Buncefield in-scope fuel storage tanks. Recommendation 8 states that industry should investigate alternative methods of tank level measurement and level detection.

Mr Jeff Pearson of the Health and Safety Executive's (HSE) Hazardous Industries Directorate (HID CI4) commissioned HSL to investigate existing and alternate tank level detection, and level storage technologies suitable for use with Buncefield in-scope substances. This was in response to recommendation 8 from 'The Buncefield Incident 11 December 2005, The final report of the Major Incident Investigation Board, Volume 2' report.

Objectives
There are a number of ways in which the gasoline and other 'Buncefield In-scope' substances stored in tanks can be measured in terms of level of tank filled. This report describes the main methods of level measurement available in the UK and highlights their shortcomings. Evolving technology and concepts that may be used on fuel storage sites in the future are also discussed.

Method
To fulfil the requirements of this project, the authors identified the current range of technologies used at Buncefield-type sites using a questionnaire HSE sent out to all the UK Buncefield-type sites. The authors investigated these methods and discussed potential problems associated with them with leading industrial experts. The authors then discussed the latest technologies suitable for use with bulk storage of gasoline. Hence we identified how potential issues associated with existing technologies can be overcome using alternative technologies.

Main Findings
Dip tapes are still a highly regarded method of level measurement in gasoline storage tanks, despite the scope for measurement inconsistency. Dip tapes are also used in the initial installation and calibration of many automatic tank gauging systems.

It was found that out of the methods identified the main level measurement systems used in the gasoline storage industry are:

- Servo-operated float gauges;
- Radar tank gauges;
- Air bubblers;
- Surface detector gauges (plumb-bob);
- Float-operated, wire-guided, inductively coupled gauges.

From those named, radar level measurement and servo gauge level measurement systems are by far the most commonly used by the UK gasoline fuel storage industry. Gasoline does not have a major detrimental effect on servo-operated float gauge systems, so long as care is taken to ensure that suitable materials are used for seals and gaskets. However some corrosive bio-fuel additives can damage these gauges. This can be problematic because over the serviceable life of some tanks they may be used to store both bio-fuel and gasoline.

Level switches which are normally associated with high or 'Hi-Hi' level detection or alarm initiation for gasoline storage tanks were:

- Vibration switches;

- Displacer (limit) switches;
- Mechanical (limit) switches;
- Optical level switches;
- Magnetic reed switches.

The most commonly encountered level switches on gasoline storage sites are magnetic reed switches.

Developments by manufacturers point towards increasing the accuracy of level measurement by combining gauging methodologies so that the shortcoming of one system is compensated for by the other. An example of this is the combination of capacitive level measurement and radar level measurement. There is also now an emergence of the magnetostrictive level measurement system, as used on petrol station forecourts for custody transfer. Until recently this method was not viable because it was not possible to manufacture the system components on the scale required for bulk storage tanks.

1 INTRODUCTION

The Major Incident Investigation Board (MIIB) was formed to investigate the Buncefield incident of December 2005. Its purpose was to make recommendations to help ensure that this kind of incident does not occur again in the future. The MIIB made a number of recommendations associated with the design and operation of Buncefield in-scope fuel storage tanks. This work considers MIIB Recommendations 8 and 13 stated in both 'The Buncefield Incident 11 December 2005, The final report of the Major Incident Investigation Board Volume 2' and in 'Safety and environmental standards for fuel storage sites, Process Safety Leadership Group, Final Report'.

The purpose of this report is to present the current methods and technologies used by industry for implementing tank gauging systems. The report will focus on tank gauging systems and level detection systems that can be implemented for 'in-scope Buncefield substances' storage facilities.

1.1 MIIB RECOMMENDATION 8

'The sector, including its supply chain of equipment manufacturers and suppliers, should review and report without delay on the scope to develop improved components and systems, including but not limited to the following:

- Alternative means of ultimate high level detection for overfill prevention that do not rely on components internal to the storage tank, with emphasis on ease of inspection, testing, reliability and maintenance.
- Increased dependability of tank level gauging systems through improved validation of measurements and trends, allowing warning of faults and through use of modern sensors with increased diagnostic capability.
- Systems to control and log override actions.'

1.2 MIIB RECOMMENDATION 13

This recommendation is primarily concerned with gas/vapour detection for loss of primary containment.

'Operators of Buncefield-type sites should employ measures to detect hazardous conditions arising from loss of primary containment, including the presence of high levels of flammable vapours in secondary containment. Operators should without delay undertake an evaluation to consider the following:

- Installing flammable gas detection in bunds containing tanks into which large quantities of highly flammable liquids or vapour may be released.
- The relationship between the gas detection system and the overfill prevention system. Detecting high levels of vapour in secondary containment is an early indication of loss of containment and so should initiate action, for example through the overfill prevention system, to limit the extent of any further loss.'

Recommendation 13 also recommends the use of CCTV equipment. However this is outside the scope of this report.

1.3 APPROPRIATE BRITISH STANDARDS

There are a number of guidance and standards publications available that should be considered by establishments that use storage tanks for ‘in-scope Buncefield substances’. Those of particular interest include the following.

- BS EN 13616:2004 Overfill prevention devices for static tanks for liquid petroleum fuels

  This standard states the minimum performance requirements expected for overfill prevention systems for static tanks no greater than 5 m in height. This standard specifically covers devices that are to be used in the temperature range –25 °C to 60 °C under ‘normal’ operational pressure variations, and tanks that are manufactured in their entirety on a production line. This is in contrast to tanks that would be manufactured in sections and then assembled upon delivery to site.

- BS ISO 4266-1:2002 Petroleum and liquid petroleum products – Measurement of level and temperature in storage tanks by automatic methods. Part 1: Measurement of level in atmospheric tanks

  This standard provides guidance on the ‘accuracy, installation, commissioning, calibration and verification’ of tank gauging systems that are used for the measurement of petroleum and petroleum products with a Reid vapour pressure of less than 100 kPa, stored in atmospheric tanks. Although this sounds very specific, it covers the majority of ATG and level measurement systems used in the fuel storage industry.

- API 2350 Overfill protection for storage tanks in petroleum facilities

  This document provides guidance for the design and installation considerations required for the use of wireless communicated systems in level measurement applications. Specific topics covered include:

  - System reliability and availability;
  - Radio emissions;
  - Radio (FCC) compliance;
  - Wireless security;
  - Explosion safety;
  - Power supply;
  - Lightning protection.

- BS EN 61511 parts 1, 2 and 3 Functional safety in the process sector.

This standard should be applied to the assessment, development and operation of safety instrumented systems (SIS) employed at Buncefield-type sites.

2 PURPOSE OF THIS RESEARCH

The purpose of this work is to present an overview of tank level measurement and level detection methods used currently in the fuel storage industry. This includes new alternative methods that aim to limit the failures known to be associated with older and some existing technologies. It does not aim to provide a detailed or definitive reference, but rather a quick reference guide that identifies common systems used in the gasoline storage industry, their shortcomings, and what new technology is available that can improve upon them.

Below are examples of significant real world incidents, which in some way were contributed to by insufficient or lack of tank gauging, level measurement or leak detection systems. Although it cannot be definitively stated, if adequate well maintained systems were in place on these sites the implications of the incident may have been significantly reduced, or even avoided altogether.

Mention of the Jaipur incident is included in this report because although its occurrence is not associated with level measurement or level detection system failure, it further demonstrates that the Buncefield incident was not unique in terms of the generation and subsequent ignition and explosion of a large unconstrained vapour cloud.

2.1.1 Hertfordshire Oil Storage Terminal, Buncefield

This incident occurred on 11th December 2005 on the Hertfordshire Oil Storage Terminal near Hemel Hempstead in England. The incident was the result of a storage tank overfill that formed a dense vapour cloud which subsequently ignited and exploded. The MIIB has officially stated that the reason the overfill occurred was because the level measurement gauge on the tank did not alter in a three-hour period, despite the fact it was being continuously fed unleaded petrol via a pipeline from the Lindsey Oil Refinery in Lincolnshire. The third progress report as presented in The Buncefield Incident 11 December 2005, The Final Report of the Major Incident Investigation Board, Volume 2, stated that findings of the investigation into the instrumentation and controls confirmed this[1]. It emphasised that in the three-hour period prior to the incident, the level gauge of this tank remained static, despite there being a continuous transfer to it.

This loss of containment (LOC) incident was in part due to shortcomings in the control and instrumentation, and in particular the failings of the tank gauging system in place on the tank that monitored the level of fuel stored in that tank. A major outcome from this investigation was the issuing of a safety notice on the type of switch used on this tank gauging system. The safety alert issued by HSE on 4th July 2006 can still be viewed online at http://www.hse.gov.uk/comah/alerts/sa0106.htm. The safety alert note names the actual type of switch and its manufacturer, and strongly advises against their use on COMAH oil/fuel storage sites. The various switches commonly used in tank gauging applications will be discussed later in this report.

2.1.2 BP, Texas City

This incident happened on 23rd March 2005 at the BP Texas City refinery, Texas, USA. This incident occurred primarily because of shortcomings in the level measurement instrumentation on the Raffinate Splitter Tower. In essence the level monitor was set up to alarm once the tower contents level reached 10 feet. Although the level monitor did alarm at this level, this event resulted in heavy hydrocarbons completely filling and overflowing the tower.

[1] *Ref: Buncefield report-Green section, page 11, paragraph 21 &22*

Human factors issues were also highlighted as being contributors to this incident. The details of this incident and the factors which contributed to it are beyond the scope of this report, but the Baker report, the Mogford report and the CBS report all give detailed accounts and expert opinions on this incident.[2] Fifteen people died and 170 were harmed as a result of this incident.

2.1.3 Indian Oil Corporation, Jaipur

This example is included in this report because of the details of the explosion that occurred, not the instrumentation factors on this site.

This incident happened on 29th October 2009, at Indian Oil Corporation's (IOC) petroleum terminal in Sitapura industrial area of Jaipur City, Rajasthan, India. Although 11 fuel storage tanks burnt down, the fire was retained on the terminal and did not spread to neighbouring sites. The cause of this incident has not yet been officially stated[3]. However it has been implied that poor operational practice, use of inadequate and faulty equipment, poor safety auditing, and lack of leak detection systems all contributed to the eventuality of this incident[4]. It has been officially stated that the fire was the result a leak of motor spirit, which ignited during a routine pipeline transfer of motor spirit and kerosene to a neighbouring installation. Eleven people died in this incident, with a further 150 others injured.

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[2] *http://www.hse.gov.uk/humanfactors/topics/texascity.htm accessed on 26th August 2009*
[3] *http://www.iocl.com/MediaCenter/Battling_the_odds_in_Jaipur.aspx accessed on 26th August 2009*
[4] *http://www.khabarexpress.com/02/02/2010-224054/Human-error-caused-Jaipur-IOC-terminal-fire-probe-shows-news_135247.html accessed on 29th September 2009*

3 TANK LEVEL MEASUREMENT METHODS: CURRENT & EMERGING

Tank gauging measurements are normally performed for one of the following reasons:

1. Operations. The main reason for this type of level measurement is to attempt to avoid unintentional overfilling or emptying of the tank during everyday operations. This form of measurement would tend to be continuous, and act as a monitor. It is also possible for this type of application to initiate alarms[5].

2. Stock control. This requires a higher level of measurement accuracy than that used for operational monitoring because it is used to account for all quantities of product on site. This type of system is used for applications such as leak detection or ensuring that onsite product quantities do not exceed those permitted. This application can operate in either continuous or periodic modes.

3. Custody transfer. This generally requires the highest accuracy level measurement because it is normally associated with the trading of the product. This application of tank gauging would be continuous, but only be used when a transfer was required.

Of the three applications in which tank gauging is normally applied, there are two general modes of operation;

- Periodic: Level measurement is performed after predefined intervals or under demand.
- Continuous: The level of the tank contents is always being measured by the level measurement instrumentation.

The design and required application would ultimately dictate how the particular system operates.

3.1 UNCERTAINTIES IN TANK GAUGING

There are numerous factors that affect the accuracy of tank level measurement. Common uncertainties include but are not limited to[6]:

- Positioning of the measurement system on and around the tank. For example, temperature measurement from a single sensor may not be sufficient if the tank and its contents are susceptible to temperature stratification. Positioning of a radar device may not account for the tank infrastructure;
- Position of the tank in the environment with respect to weather factors such as wind, heat and abnormal pressure;
- Tank construction should consider pressurisation at the design stage.

3.2 APPROVALS OF SYSTEMS AND COMPONENTS[7]

In the UK, inspectors from HM Revenue and Customs certify each system individually to ensure that the measurement system in place on the storage tanks is of sufficient accuracy for custody transfer. Therefore whenever maintenance is performed, recertification is necessary.

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[5] *Berto FJ (1997). Review of Tank Measurement Errors Reveals Techniques for Greater Accuracy. Oil and Gas Journal 1997, Volume 95, Issue 9, pp68-73.*

[6] *Enraf B.V. The Art Of Tank Gauging. The Netherlands: Enraf B.V, Delft vW-IN-44 16.650-V4*

[7] *Meeting with industry specialists. Meeting minutes 16th November 2010.*

MMI (German) and PTB (Dutch) are internationally recognised standards that are used and referenced in the world of level measurement, and apply to the certification weights and measurements.

The purpose of tank gauging is two-fold:

1. To gauge if the contents of a storage tank are within safe limits;
2. To accurately know the quantity of product in a container for inventory and stock control.

The certified equipment is as follows.

- For Buncefield-type applications (i.e. gasoline storage) the tank side of the level measurement system is classified as a generally hazardous area (ATEX/DSEAR). At the very least the electrical and instrumentation installation require the use of ex-rated equipment.
- Safety Integrity Level (SIL) ratings are not generally associated with tank level measurement equipment and is not of great significance for tank storage control systems, although relevant for Buncefield-like installations. Similarly to the process industry, SIL ratings are sometimes misquoted as referring to a component, rather than the system as a whole.
- Safety systems can be approved or certified by an independent third party. Certification bodies that are commonly used in the UK include, but are not restricted to,:
    - TUV Rhineland;
    - Exida (popular choice);
    - SIRA.

Certification of the level measurement system components demonstrates that the system has been implemented with consideration given to guidance such as BS EN 61511 Functional safety - Safety instrumented systems for the process industry sector.

3.3 CURRENT LEVEL MEASUREMENT SYSTEMS

There are a number of level measurement system technologies which are used for liquid level detection. The main types, as identified by Instrument Engineers' Handbook Process Measurement and Analysis Volume 1, 4th Edition by Liptak, are discussed here. Appendix 4 provides an overview table of the main level measurement methods used in the fuel storage industry. The most commonly encountered level measurement systems used in the gasoline storage industry are currently radar systems and servo gauge systems[8].

A basic and commonly used way of measuring the liquid level within a storage tank is measurement by dip tape. This is a single manual measurement that is performed by an individual. The accuracy of the measurement taken is dependent upon the skill and experience of the individual, and therefore there may be inconsistencies between different individuals. Any manual process can be subject to human error, so suitable procedures should be put in place to counteract this.

Presently, radar technology is most commonly used in the fuel storage industry, although servo gauging systems are also very common. The main reasons for radar being favoured over mechanical and float type systems is that it has no moving parts and is non-invasive. This leads to higher reliability due to the removal of factors such as wear and tear of moving mechanical components.

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[8] *Meeting with industry specialists. Meeting minutes 16th November 2010*

3.3.1 Dip tape level measurement

A dip tape is a manual user-operated liquid level measurement device, which consists normally of some form of calibrated tape, for example metres, feet, yards, with a weight attached to the end. The weight is lowered into the tank inside a stilling well until the operator feels the weight touch the bottom of the tank, at which point the grading on the tape is read. The tape is then retracted whilst the operator sees where the tape is wet. The grading on the tape is then noted again. The difference between the two recorded values is then noted. Using dimensional and capacity information known about the tank, the height of the tank which is empty, the ullage, can be calculated and be expressed as a percentage of the overall tank capacity. Dips are normally taken at a stilling tube, using a plumb bob with a point contact to locate the tank bottom by feel. There is usually a striker plate fixed to the tank base that acts as the datum. There have been cases where the absence of a striker plate allowed the bottom of the tank to be holed by regular impact from the plumb bob, resulting in the loss of considerable quantities of fuel[9]. Accuracy and consistency is highly dependent on the operator. Dip tapes have been the traditional method of measuring tank contents, but newer automated technologies have taken over because they can offer continuous level monitoring.

The accuracy of the measurement using this method is likely to vary depending upon operator skill and experience. It is possible to achieve ±1 mm accuracy in theory with this manual method, however this is very rarely achieved in practice. HM Revenue and Customs presents 'HCOTEG177700 – Measurement: Tank dipping' on its website http://www.hmrc.gov.uk which highlights a number of considerations that can contribute to manual tank dipping measurement inaccuracies. It also states the requirements for official tank dipping for custody transfer and revenue assessment. In addition to the information presented by HM Revenues and Customs, accuracy of dipping measurements can be adversely affected by high winds and cold temperatures. Tank dipping is still highly regarded in the storage industry. The process that is generally adopted for dipping a tank is that three consecutive dips are performed. If there is significant variation in measurement further dips will be performed until such a time that the measurement is consistent. There can be a number of reasons why variation in measurement can be introduced. For example, operator to operator variation in technique, or even the physical height of the operator. If operator A is 6'5, and operator B is 5'4, there is potentially a significant variation in measurement reference point.[10]

This is a quick level measurement method but should only be used as a means of double-checking a measurement made by a different method. It should not be a fuel storage site's only means of determining tank levels. However, this method is used in the setup of radar and servo level measurement systems and is still highly regarded.

Some dutyholders dip the tank before and after a transfer. This is an independent verification of the quantity of product transferred. The exercise performed can also be used to 'realign' the tank measurement gauges.

3.3.2 Float-operated, wire-guided, inductively coupled

This type of system is an old method of level measurement used in the fuel storage industry. This system has a wire that is fixed at both the top and bottom of the tank, and is used as a guide and a source of power for the float. The float contains an inductively coupled transducer, powered by the guide wire. During operation the primary coupling of the transducer is periodically interrupted, allowing a secondary inductive coupling of the transducer between the

[9] *Griffiths P. Private communication. 11th May 2010*
[10] *Meeting with industry specialists. Meeting minutes 16th November 2010*

wire and float transducer. Measurement is achieved though conductors placed at known intervals on the guide wire, which produces a 'grey' encoded word that is then communicated back up to the display unit.

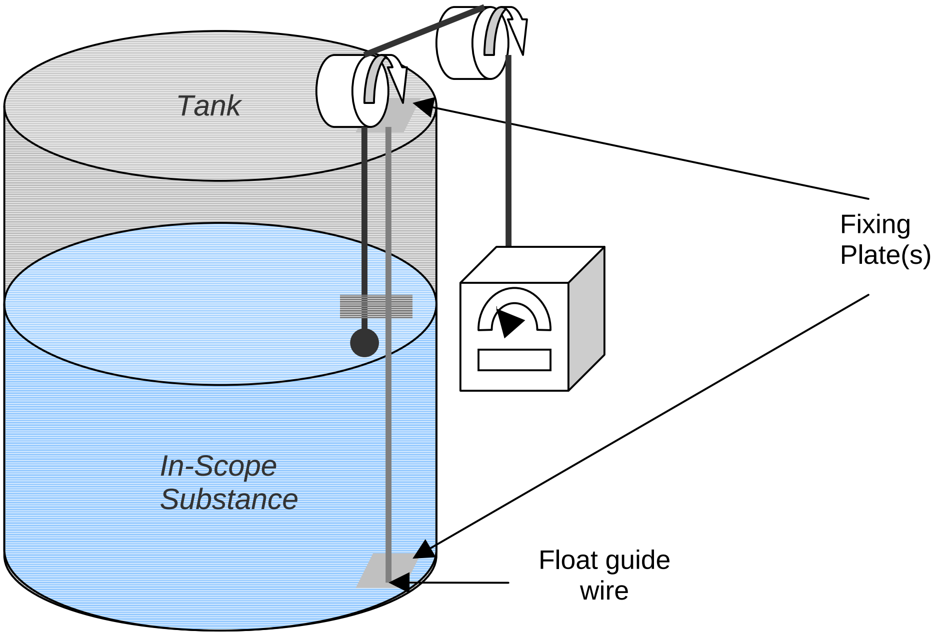

Figure 1 Simple diagram to demonstrate a float type level measurement system

This type of system should only be used in 'clean' measuring applications, therefore it is suitable for gasoline level measurement.

This is a widely used level measurement method, however its perceived accuracy is not considered good enough for either custody transfer or stock accounting measurement[11].

Another drawback with inductively coupled wire guided floats is that they can be prone to 'tape hang-ups'. This can occur when material builds up on the guide wire which then hinders the movement of the float. This problem would become worse with viscous material measurement.

Components of inductively coupled wire guided float systems are prone to accelerated wear because of continuous movement of the drive mechanism that is connected to the float on the liquid surface. Therefore the level of reliability of this method can be potentially poor. Industry experts spoken to suggest that this method of tank gauging should no longer be used because of the varying levels of reliability and accuracy of measurement, and the method's high maintenance demands[12].

Float systems are becoming less commonplace mainly because evolution of the other methods has advanced further than this method. Over time, as these systems break down, many fuel storage facilities are choosing to replace this type of system with different technology[13].

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[11] *Rowe JD (1991).* Automatic Tank Gauges. *66th International School of Hydrocarbon Measurement 1991 Proceedings, 01457594, pp402-405*
[12] *Enraf B.V.* The Art Of Tank Gauging. *The Netherlands: Enraf B.V, Delft vW-IN-44 16.650-V4*
[13] *Meeting with industry specialists. Meeting minutes. 16th November 2010*

3.3.3 Servo-operated float type

Servo-operated float level measurement systems use fluid displacement for continual measurement. This method is considered more accurate than wire-guided float systems and surface detector (plumb-bob) systems.

The servo gauge is used to move a displacer that is continually measuring the liquid in the tank. This is done by driving the displacer through the tank's open space until it makes contact with the liquid surface. As the liquid level in the tank changes the system always aims to maintain the displacer in equilibrium, which produces the level measurement. In addition to performing level measurement this type of system is capable of raising alarms, such as high-high, low-low.

The material composition of the float can have an effect upon the accuracy of 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.
>
> **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.

This method has a long and successful history of being implemented in 'clean' measurement applications such as the gasoline storage industry. The initial setup of this type of system is critical in ensuring an accurate level measurement is achieved. The setup process requires the tank to be manually dipped. This allows for offsets to be determined and applied to the instrumentation appropriately[14]. Correct setup and maintenance does allow servo-operated float systems to be used in custody transfer, inventory and density measurement applications.

Although this is a well-established level measurement method there are still a number of limitations with this method. For example, to provide 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. However, if this is adhered to, servo-operated float systems can be reliable and highly accurate.

Servo-operated float systems are also fragile instruments. Vibration caused by people walking or even standing on a tank roof to which they are attached can cause the instrument to bounce and fall out of calibration.

Wire snapping is another common problem with this type of system. However this fault is normally instantly acknowledged. In a stilling well, the displacer may rest on the side of the pipe if, for example, the tank foundation subsides[15].

It is common practice in industry to test this type of level measurement device by manually driving the float to the top of the tank and then allowing the float to return down to the liquid surface. This test method is used when it is suspected that the level measurement provided is incorrect. It is a simple initial check to perform instead of dip taping the tank. Modern servo-operated float gauges have functions built into them to drive the float to the top to ensure a measurement occurs. This and other similar features are built into these newer gauges to make them readily testable. This aims to overcome the systems not being tested because of perceived complexity of the systems by the operators.

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[14] *Meeting with industry specialists. Meeting minutes. 16th November 2010*
[15] *Meeting with industry specialists. Meeting minutes. 16th November 2010*

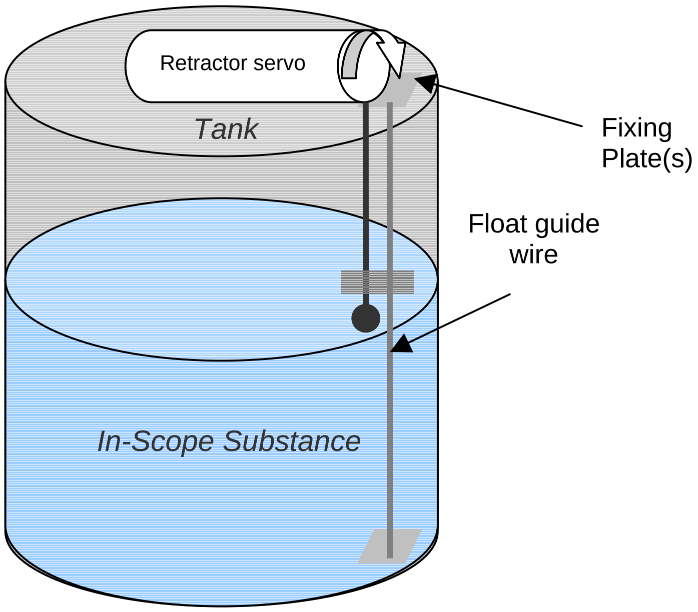

Figure 2 Simple diagram to demonstrate a servo-operated float type level measurement system

Latest version of the technology
Currently servo gauge level measurement systems are approved by a number of European governments and agencies for custody transfer because of the accuracy that these measurement systems can achieve[16]. Accuracy in the order of mm can be achieved using servo-operated float gauges for level measuring gasoline[17].

The perceived problems with servo-operated float level measurement systems fall into the category of maintenance and mechanical wear:

Maintenance issues
The activities involved are not complex, but do require attention whilst maintenance is being performed. Once maintenance has been performed, it must be ensured that the gauge is behaving as expected, and a balance weight calibration is performed to ensure that the level measurement is accurate.

Gasoline does not have a major detrimental effect on servo-operated float gauge systems as long as care is taken to ensure that suitable materials are used for seals and gaskets. However, the same cannot be said of the effect of bio-fuels. Due to some corrosive bio-fuel additives these gauges can be damaged. This can be problematic because some tanks may be used to store both bio-fuel and gasoline at different points in their service life. This change over may not be captured in a company's management of change procedures and as such may not be subject to impact analysis or risk assessment.

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[16] *Rowe JD (1991). Automatic Tank Gauges. 66th International School of Hydrocarbon Measurement 1991Proceedings, 01457594, pp402-405*
[17] *Meeting with industry specialists. Meeting minutes. 16th November 2010*

Mechanical wear
This technology relies on many mechanical parts, all of which are prone to wearing out over time in service. These parts are typically the servo motors, gear train, and magnetic bearings. Wear of these parts is normally detected by erratic measurement or sticking of the float. Annual maintenance will also allow worn parts to be identified and repaired, or replaced as required. Wear can be accelerated when the stored gasoline or other Buncefield in-scope substances come into contact with the equipment, increasing the onset of rust on metallic parts. In some cases this could also lead to measurement offset.

For gasoline level measurement the float must be in contact with the surface of the gasoline. This is primarily required so that the sensors within the float can determine if the surface is gasoline or surface water.

Error in measurement can be caused by system software. It is likely that a failure in the software that is associated with buoyancy would lead to measurement inaccuracy.

3.3.4 Surface detector (plumb-bob) gauges

A 'plumb line' weight is lowered from the sensor unit, which is fixed to the top of the tank, until the weight makes contact with the surface of the contained material. The weight is then retracted into the sensor unit whilst the line is measured. The resulting measurement is then used to calculate the level of material present in the tank.

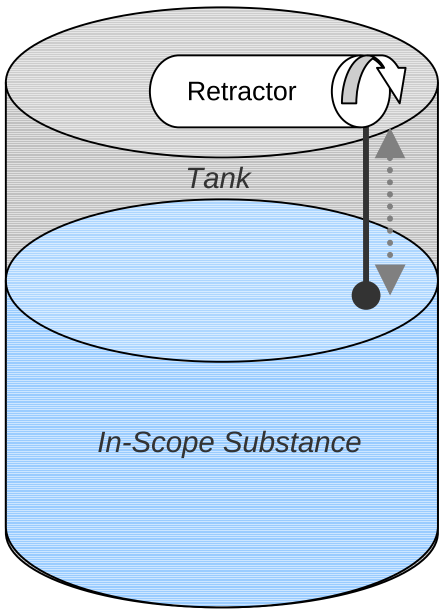


Figure 3 Simple diagram to demonstrate a surface detector level measurement system

Unlike servo-operated float gauges that provide continuous measurement, surface detectors are periodic measurement systems.

The most commonly reported problem with surface detector level measurement systems is that the plumb weight can become jammed in the sensor unit.

Similarly to float-operated wire-guided systems, this method's components are prone to accelerated wear because of continuous movement of the float on the liquid surface, which applies continuous movement on the mechanical components. Therefore, the level of reliability of this method is potentially poor.
It is suggested by industry experts that both the system designers and manufacturers consider this method of tank gauging should no longer be used because of the varying levels of reliability and accuracy of measurement, and the methods high maintenance demands[18].

3.3.5 Radiation backscatter design (non-invasive)

This method of level measurement has a radioactive source as transmitter and is paired with a detector at the opposite outside of the tank. To determine the level of material, the detector looks for a 'scatter pattern' that is consistent with the organic material within the tank. This technology is generally not used in the gasoline storage industry because comparable measurement accuracy can be achieved with servo-operated float gauges or radar systems at a lesser financial outlay for initial purchase, installation, periodic inspection, and without the perceived hazards associated with radioactive sources present on site. An additional consideration with these systems is that due to the radioactive sources, utilised licensing is often required.

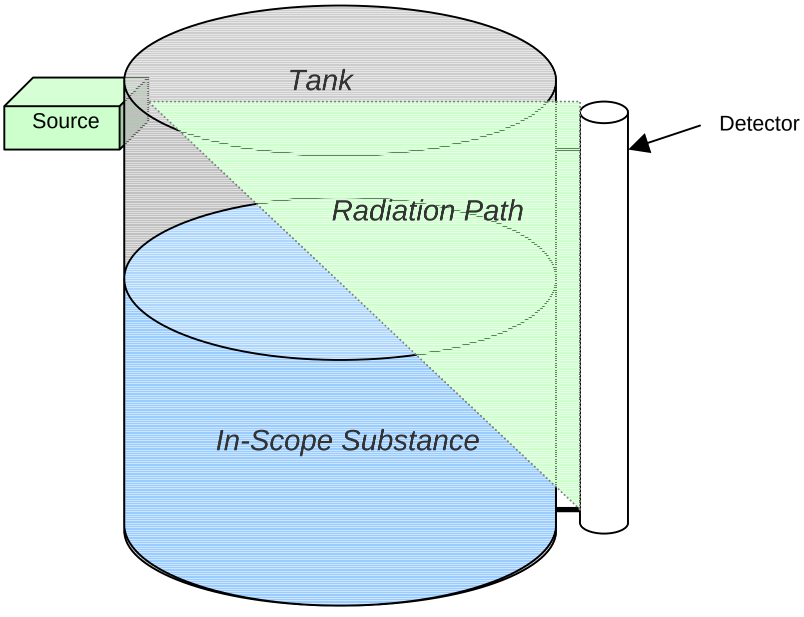


Figure 4 Simple diagram to demonstrate a radiation level measurement system

This is a preferred system of measurement for highly corrosive materials because it does not expose the measurement system directly to the contained material.

[18] *Enraf B.V. The Art Of Tank Gauging. The Netherlands: Enraf B.V, Delft vW-IN-44 16.650-V4*

3.3.6 Radar tank gauges

Radar tank gauging is currently one of the most popular level measurement methods used in the gasoline storage industry. Radar level measurement 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[19]. A fundamental drawback with radar systems is 'blocking distance'. This is the term given to the instance where the tank contents level gets too close to the radar device so that it is no longer possible for the transmitted radar signal to be reflected back from the liquid surface to the detector in a meaningful way[20].

Radar systems have no moving parts, and as such incur little mechanical wear when compared to servo gauge technology. However because these systems have an electronic contingent, ageing of circuit components can become a potential cause of system failure.

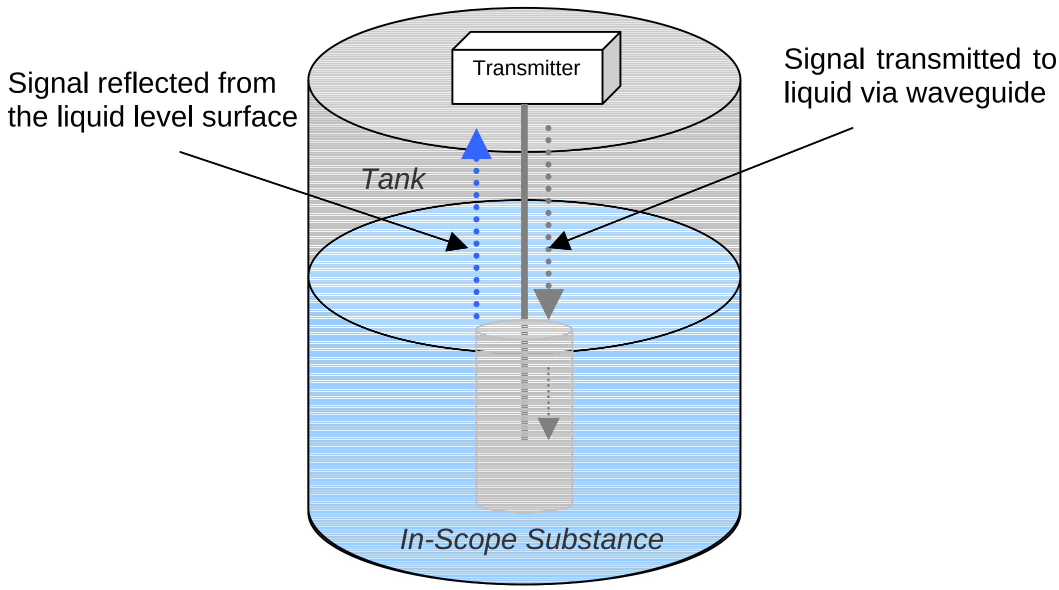
First generation radar level measurement systems are still providing accurate measurement up to 30 years on from the initial installation. An advantage that radar systems offer over servo gauge systems is that as they age during time in service it becomes more cost effective to repair radar systems when compared to the repair costs that would be expected for a similarly aged servo gauge system carrying out the same activity.

There are two variants of radar level measurement systems that are used in the gasoline storage industry. They are:

- Radar tank gauges (contacting);
- Radar tank gauges (non-contacting).

Contacting

As the name suggests, this method of radar tank gauging requires the system to come into contact with the liquid being stored.



[19] *Enraf B.V. The Art Of Tank Gauging. The Netherlands: Enraf B.V, Delft vW-IN-44 16.650-V4*
[20] *Schnake J (2007). Liquid Level Measurement – Basics 101, Part 2, White Paper Endress & Hauser available as a download from http://www. controlglobal.com/wp_downloads/pdf/071102_wp_Endress_LiquidLevelPart2.pdf , accessed 22nd November 2010*

Figure 5 Simple diagram to demonstrate a contacting radar level measurement system

Contacting radar gauges have a probe, known as a 'waveguide' in the tank, which is used to perform the measurement by transmitting a periodic pulse. The transmitted pulse will reflect off of the surface of the stored gasoline, which in turn is detected by a sensor using one of the following methods:

1. Time Domain Reflectometry (TDR);
2. High efficiency low power, DC sensing methods. These include:
   a. Guided wave radar (GWR) based upon TDR;
   b. Phase Difference Sensor (PDS), determines level from change in phase angle of material in container.

Non-contacting

Non-contacting radar level measurement does not employ a waveguide to transmit the radar signal to the stored liquid surface; it transmits the radar signal directly into the free space of the storage tank. The signal is then reflected back to detectors mounted within the tank, out of reach of the stored material. This method of tank gauging is often incorporated into a stilling well. A stilling well is a more controlled environment in which to perform level measurement. The radar propagates deeper in a stilling well than it does in the main tank. This removes the potential for misreading due to false echo caused by internal tank obstacles. However, using stilling wells requires the radar transmitter to have a parabolic cone to direct the signal. This is to minimise the possibility of false echoes occurring in the measurement due to reflections off the stilling well wall.

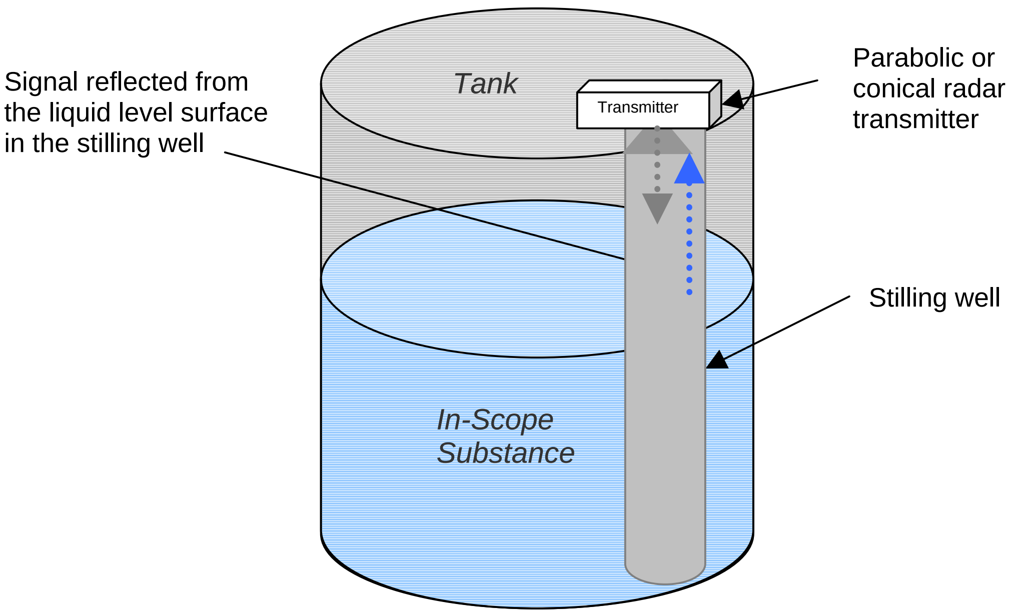


Figure 6 Simple diagram to demonstrate a non-contacting radar level measurement system

Testing of radar level measurement systems

A method of testing a radar level measurement system, suggested by a reputable manufacturer, is to place a steel plate a known distance away from the transmitter. The transmitted signal is then reflected from the metal plate instead of the liquid surface. This is a preferable means of testing the system because it can be conducted in situ, but not involve the operator having to interact with the stored material and the associated safety implications.

It has been suggested that radar systems are particularly suitable for the level measurement of products with a low dielectric constant, for example products like LNG and LPG. Guided radar level measurement systems, if set up correctly, can achieve measurement accuracy of up to 2 mm for process level measurement. Higher accuracy can be achieved for fiscal measurements if required.[21]

System integrators who specialise in gasoline level measurement applications suggest that radar systems are one of the most favoured methods of level measurement used in the gasoline storage industry at present. It works best for tanks that only store one type of product (referred to as ‘fixed service’). Its advantage is that there are no moving parts and is fairly low cost.

A disadvantage of the radar systems is that they can be problematic to install and set up correctly. Problems with radar systems are generally experienced at the installation phase of the lifecycle. These can be due to vapour being present or obstructions in the tank which cause false echoes. Therefore, the design of a radar level measurement system is very important and systems designers have to give consideration to where transmitters and receivers are placed to minimise effects of factors like vibration and echoes. A successful installation of a radar system would require the tank to be completely filled and discharged in order to determine level measurement accuracy. However in practice this is rarely practicable because the tanks will generally contain some material, so delayed indication of level measurement problems can occur.

When tanks are very full or very near to empty, accuracy is greatly reduced because of tank reflections. Tank reflection is where the returning signal is bounced back from a surface other than the product surface as intended. Reflections can come from tank walls, instrumentation housing that is invasive to the tank or, most commonly, tank furniture/fittings such as internal staircases. Inaccuracies in measurement can also be experienced if the product in the tank is rippling because it causes the return signal to scatter and disperse or take longer to reach the receiver. Although this is a noted issue, newer versions of this type of radar system compensates for the product rippling effect.[22]

Tall narrow tanks are a problem for radar systems, and therefore the radar transmit beam spread/width is critical. However accuracy in the order of ±1 mm can be achieved with correctly installed and well-maintained radar level measurement systems, which is comparable to servo gauge systems measurement accuracy.

System integrators have highlighted that common causes for degradation in measurement accuracy over time can be attributed to the following causes. However it should be noted that these named causes are not normally associated with the storage of gasoline.

- The signal to noise ratio (SNR) can increase over time due to crystallisation of the stored product. This is not an issue for gasoline storage, but should be acknowledged for this type of system.
- The stored product, again gasoline is not an issue, can corrode the antenna resulting in degradation of measurement accuracy.

This method of level measurement has been shown to measure erroneously up to 10mm/m in the presence of light hydrocarbon materials. Radar level measurement used with heavy

[21] *Meeting with industry specialists. Meeting minutes. 18th November 2010*
[22] *Meeting with industry specialists. Meeting minutes. 16th November 2010*

hydrocarbon materials does not experience errors of this magnitude assuming it is designed and set up correctly for the application. As an aside note, although gasoline storage tanks do not contain such equipment, another source of measurement inaccuracy experienced with radar systems is interference from process equipment like tank agitators.

3.3.7 Capacitive tank gauges[23]

A constant voltage is applied to a metallic probe within the tank. The corresponding current is then monitored. This current is proportional to the capacitance from the metallic probe to a second electrode. The second electrode is generally a wall of the tank.

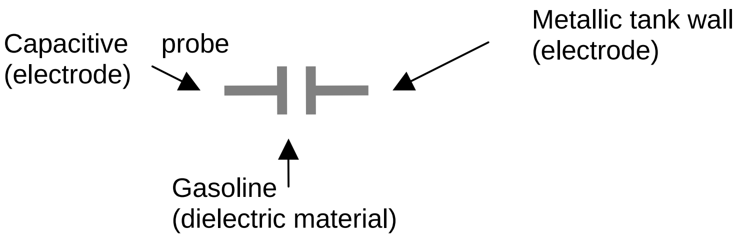
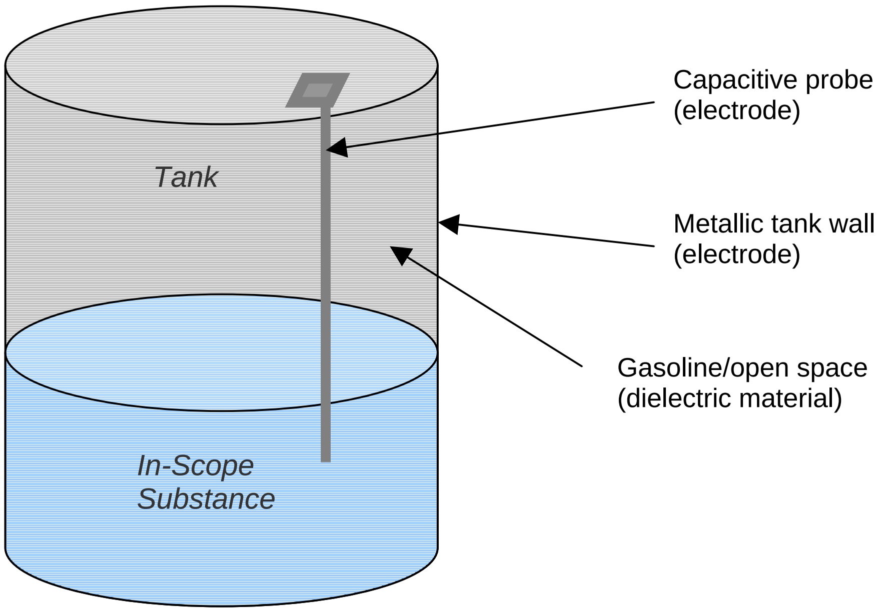


Figure 7 A capacitor interpretation of the elements of a capacitive level measurement system

False high level indications are a typical failure mode of this type of system. This kind of failure can be caused by one of the capacitive plates becoming coated with a material, such as the product being stored, to such an extent that the sensing element becomes connected to the ground. Apart from the issue of plate coating, the capacitive level measurement system experiences very little operational degradation. This is because there are no moving parts.



[23] *Liptak BG (2003).* Instrument Engineers' Handbook Process Measurement and Analysis Volume 1, 4th Edition, *CRC Press ISBN 0-8493-1083-0*

Figure 8 Simple diagram to demonstrate a capacitance-based level measurement system

3.3.8 Hydrostatic tank gauges

Hydrostatic tank gauging (HTG) has historically been a cheap means of level measurement that can be used in the fuel storage industry. This method has no wetted or moving parts within the tank. In addition, with modern versions, because they measure based upon volume to provide a quantity in terms of mass, an accurate level measurement is possible. This in turn provides a good means of leak detection.

Current versions of this technology also allow density of material measurement. This component is used in calculating the liquid mass, but a secondary benefit is that it allows the observation of material composition for quality control.

This is a continuous measurement method and works by measuring the pressure at two sensors which are a known distance apart in the tank. The temperature in between the two pressure measurement points is also measured.

The accuracy of the measurement that can be achieved with a correctly installed system is up to ±10 mm of the level of the tank. This is generally considered to be because of limitation induced by the pressure sensors used. Therefore, it is considered that HTG systems are a good method of providing a rough indication of tank level, but not sufficient for custody transfer measurement. It is strongly recommend that if HTG is used in level measurement or overfill protection, it should be accompanied by further secondary high level alarms.[24] It should be noted that some system designers believe that accuracy comparable to radar and servo gauge systems can be achieved but at a high financial cost, which in a lot of cases would be higher than the cost of radar or servo level measurement systems.

[24] *Enraf B.V. The Art Of Tank Gauging. The Netherlands: Enraf B.V, Delft vW-IN-44 16.650-V4*

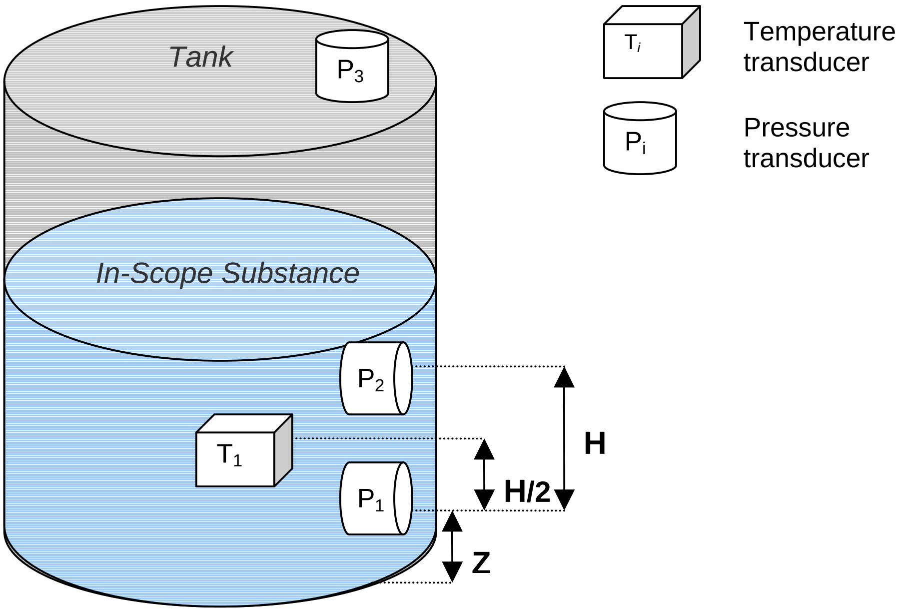


Figure 9 Simple diagram to demonstrate a HTG level measurement system

The pressure readings are used calculate the mass of material in the tank using the following series of simplified equations:

Simplified Density Equation (D)

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

where: P1 = pressure (bar) at P1

P2 = pressure (bar) at P2

H = Distance between P1 and P2 in metres

Standard Density at 15.5 °C [60 °F] (*Dref*)

$$Dref = f(D,T)$$

Simplified Standard Volume Equation (SV)

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

Simplified Level Equation (L)

$$L = \frac{(P1 - P3)}{D} + Z$$

P3 can be ignored if the pressure above the liquid is atmospheric.

Effective Tank Area (A)

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

Simplified Mass Equation (M)

$$M = A \times L \times D$$

This type of level measurement system can be used in stored fuel measurement. However, it is not a favoured level measurement system primarily due to the difficultly in maintaining measurement accuracy due to variation of temperature and changing state of the stored gasoline. The non-invasive nature of this system (that is, it has no moving parts) can be implemented using commercially available components and technology. This would make this an attractive level measurement approach if the issue of consistent measurement accuracy was addressed.

There are a number of limitations associated with HTG systems that are used for level measurement. 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.

The incorrect or insufficient installation and commissioning of an HTG system can cause significant errors in measurement. Another cause of error in level measurement is exposure to air of the pressure sensor, because this will cause the pressure induced by the air to be measured instead of the pressure of the stored gasoline. There is also a known issue with the HTG system sensor configuration where any vapour within the tank will directly affect the pressure measured and thus the measurement accuracy.

Early systems were prone to giving incorrect level measurements with variation in ambient temperatures. This was addressed in newer HTG system designs by the inclusion of temperature sensors which allowed for temperature compensation to be made in the measurement. However, even with these newer systems, there may still be inaccuracies in measurement if there are multiple materials stored in the tank which have differing temperature or density characteristics, resulting in layering of stored material in the tank.

Maintenance of HTG systems focuses mainly on the cleaning of the sensors and removal of sediment build up in the bottom of the tank, which in itself can cause an inaccurate level measurement.

It is the opinion of system designers the authors spoke to that in reality it is hard, if not impossible, to test HTG systems fully because the operator often cannot see into the tank to verify what the product level is, unless the system is installed so that it is visible from outside of the tank.

Currently, HTG level measurement is not commonly used in the UK for gasoline level measurement. However, it has been cited by the instrument engineers' handbook, Process Measurement and Analysis 4th Ed as being used in the following applications:

- Clean liquid measurement (atmospheric and pressurised);
- Hard to handle fluid measurement (atmospheric and pressurised);
- Bi-phase material;
- Cryogenic material;
- Boiling material.

Problems with HTG systems are attributable to the sensors used. Placement, maintenance and replacement of these parts are key to continued measurement accuracy. Incorrect placement of sensors can lead to error introduction, which can in turn lead to inaccurate level measurement. In order to achieve a high accuracy measurement, the pressure sensors used must be at least 20 to 30 times better (higher quality) than those used in standard process control applications. It is implied that the pressure sensors used in this application must be capable of maintaining calibration between maintenance and inspection intervals. Hydrostatic Tank Compensation (HTC) can be implemented using one pressure difference sensor, which compensates for measurement errors. This can be introduced when using two individual sensors.

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.[25]

From the experience of systems integrators spoken to, this method is seldom used in the fuel storage industry in the UK. This method uses a multi-parameter probe and is seen as being the big advantage that manufacturers are using to push this method. The main advantage of this method is due to the minimal wetted parts involved, and theoretically little or no overhead for maintenance. However in practice this is very unlikely to be the case.

It is also, in theory, straight-forward to retrofit the system to existing tanks. The equipment can be lowered into existing stilling wells. This has the advantage of being easily accessible for servicing. The system is also versatile enough to be able to use existing entries into a tank. This can, however, cause problems when routine maintenance is performed.

An American level measurement system design company puts forward a very strong case in support of HTG systems.[26] However this view is not widely shared in the UK. Further limitations of this method are introduced because of its dependence upon temperature and product density. Water in the gasoline storage tank can also lead to incorrect level measurement or misinterpretation of tank contents.

[25] *MHT information factsheet for the energy industry. Hydrostatic Tank Gauging available for download from: http://www.mht-technology.co.uk/documents/uploads/Hydrostatic%20Tank%20Gauging%20v1.1.pdf, accessed on 29th September 2009*

[26] *Meeting with industry specialists. Meeting minutes. 16th November2010*

3.3.9 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 can be affected (due to change of speed of sound) by factors such as moisture, temperature, and pressures. To overcome this, correction factors are applied to the level measurement to improve measurement accuracy.

Mounting and positioning of the ultrasonic transducer is key to ensuring the best response to reflected transmissions. Additionally the tank should be relatively free of obstacles such as brackets or ladders so that false returns are minimised.

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 tanks. Accuracy can be improved by having a fixed reference point within the tank and to instead continuously monitor the changes in level with respect to this fixed point[27].

This tank level measurement system is relatively cheap when compared to alternative systems that offer comparable accuracy.

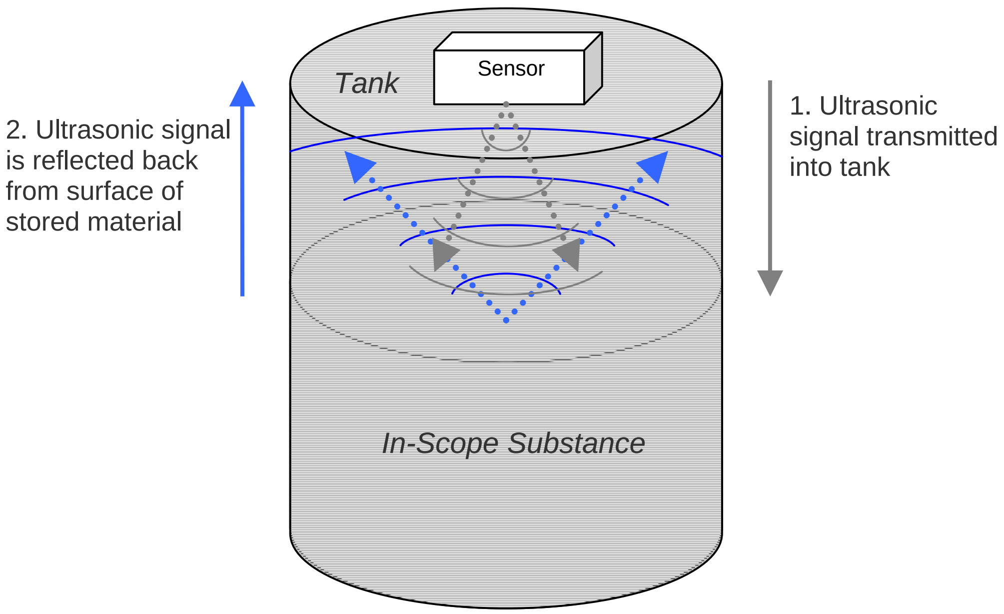


Figure 10 Simple diagram to demonstrate a ultrasonic level measurement system

[27] *Lewis WA (1994) Confusion Over Tank Gauging. Control and Instrumentation 1994, volume 26, Issue 9, pp11*

This method of level measurement is widely viewed as being inaccurate; this is caused by the effect that gasoline vapour has upon the measurement. Both system manufacturers and system solution designers and installers have stated that this technology should not be used on gasoline or any Buncefield-type fuel storage tanks.

3.3.10 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. 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 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 would be specified at the design stage to be 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; they 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.

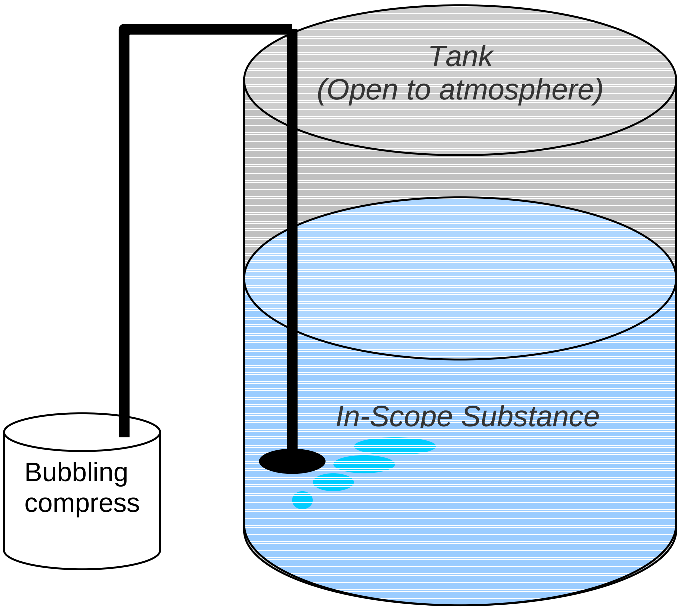


Figure 11 Simple diagram to demonstrate an air bubbler level measurement system

Air bubbler systems are used in the fuel storage industry, albeit in small numbers, but are being phased out in favour of the servo gauges and radar systems. This is partly due to the specialist requirements for maintenance of these air bubbler systems. It is also partly due to the measurement accuracy being in the order of ±10 mm. Therefore, air bubblers are not considered to be as accurate as servo or radar gauges.

Although named 'air bubblers' these systems are not limited to just utilising air. In fact, for gasoline and in-scope substance liquid measurement it is commonplace to use nitrogen instead of air. This is the preferred gas because, amongst other reasons, once it has bubbled through the flammable stored liquid it settles above the surface, providing a nitrogen blanket. This is important if the tank is open-topped because it will help prevent flammable vapour escaping.

Air bubblers have a number of moving parts that require maintenance. These parts include the valves that isolate the gas supply to the tank for bubbling. In addition to the maintenance of the physical valve, there are a number of electro-mechanical parts of the system which require maintenance, for example actuators to control the opening and closing of the valves or compressors. An advantage of the bubbler system, from a maintenance point of view, is that the work required is not at tank side, therefore reducing the exposure time of the maintenance worker to the gasoline stored in the tanks.

There are a number of known issues with bubbler systems. Operational problems can be encountered if a loss or reduction in bubbler pressure occurs. This may result in either reduced accuracy in level measurement or even total loss in measurement. From a legacy perspective, the availability of replacement parts for this type of system is becoming an issue because systems are going out of production with 'last time buy' component stocks depleting[28].

[28] *Meeting with industry specialists. Meeting minutes. 16th November 2010*

3.3.11 Thermal differential

The thermal differential system is strictly a monitoring system rather than a level measurement system. It utilises two Resistance Temperature Detectors (RTD). 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[29].

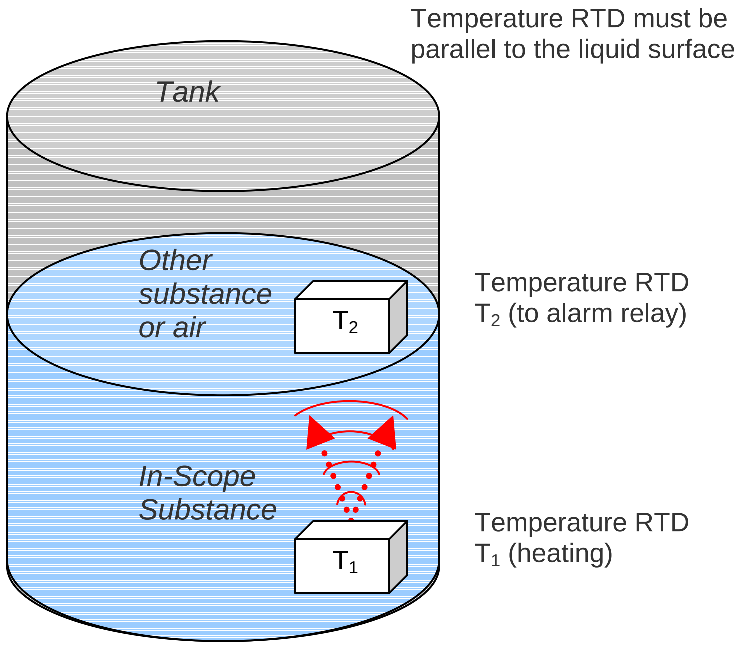


Figure 12 Simple diagram to demonstrate a thermal differential level measurement system

This type of level measurement equipment can also be used for monitoring the flow of liquid to or from the tank and for alarm initiation.

This method of tank level monitoring has no moving parts. A two-stage calibration of the monitoring probe is required. An accuracy of between 0.1% and 5% of the full scale measurement can be attained.

3.3.12 Slip tube gauging

This is an inaccurate and arguably dangerous method of level detection. Although it can be used in liquid level detection, it would not be suitable for fuel storage applications.

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[29] *www.kenco-eng.com, accessed on 4th January 2010*

The rotary method uses a head assembly which is opened until vapour is discharged from a bleed connection. When vapour is detected, a handle is turned which rotates the slip tube assembly. This is done until liquid instead of vapour is seen in the tube. The measure of liquid in the tank can be related to the position of the rotated handle.

A vertical slip tube is also available which involves the lowering of the tube into the tank until its tip touches the surface of the liquid. Once in contact, liquid will start to bleed out of the cap assembly instead of vapour. The level that the liquid reaches within the tube can be an indication of the liquid level in the tank.

3.4 NEW CONCEPTS USED FOR TANK GAUGING

In addition to the conventional ‘hardwired’ methods of tank gauging, manufacturers are beginning to develop and market wireless systems. This technology in itself brings both many advantages and drawbacks associated with radio communications.

3.4.1 New technologies used for tank gauging

A concept which Endress and Hauser have driven forward is a level measurement called the Levelflex FMP5x that combines both capacitance and radar measurement systems. Its purpose is to overcome the problems not knowing where substance transition points are within a tank. This is of importance where a tank contains an unknown quantity of water and gasoline. It can also help eliminate incorrect level measurement readings that are caused by false echoes from radar measurements. The key to this new system in providing accurate measure is the correct setup of the complete system.[30]

3.4.2 Hybrid Inventory Measurement Systems (HIMS)

This can be viewed as the ‘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 is still evolving. It stands out from conventional methods because it is able to measure level by means of any conventional automatic tank gauging (ATG), volume by pressure sensor and density, just like current HTG. Hybrids, however, utilise level measurement equipment, a ‘smart’ pressure transmitter and a temperature measurement device, which allows the volume to be calculated more accurately than can be achieved using HTG[31].

This is the most recent evolution of tank measurement methods and is suggested to achieve greatest accuracy of all present methods because it presents a synergy of existing, diverse, level measurement technology.

3.4.3 Magnetostrictive systems

This technology has been around for a long time and is used primarily for custody transfer on petrol station forecourts. In this application of magnetostrictive gauging, level measurement can be performed to a very high level of accuracy. However, at this stage of development for a larger scale version for gasoline bulk storage tanks, the accuracy of measurement is yet to be determined, although it is thought that accuracy comparable to radar and servo gauges would be achievable. It is now becoming considered by more storage industry facilities because of the perceived measurement accuracy. This has become possible because technology is available to allow probes of up to 30 m to be manufactured. This is seen as being an up-and-coming level measurement method for use in the gasoline bulk storage industry.

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[30] *Meeting with industry specialists. Meeting minutes. 18th November 2010*

[31] *Enraf B.V. The Art Of Tank Gauging. The Netherlands: Enraf B.V, Delft vW-IN-44 16.650-V4*

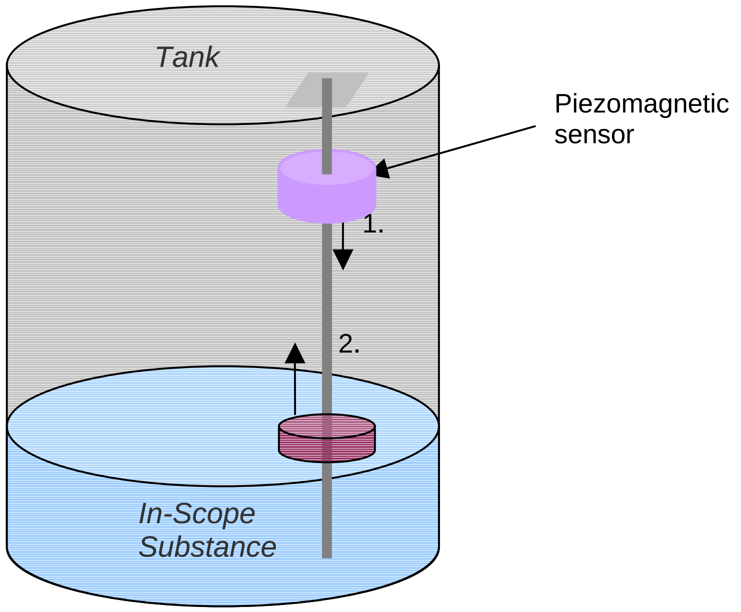

Figure 13 Simple diagram demonstrating a magnetostrictive level measurement system

1. A pulse is transmitted down the sensor wire towards the magnetic float[32].
2. The transmitted signal reaches the magnetic float, which is floating on the gasoline surface, and the signal is returned back up the transmit wire back to the piezomagnetic sensor. Since the initial transmit time and return time is known, it is possible to calculate the distance at which the float is along the sensor wire and therefore what the gasoline level is within the tank.

The perceived benefits of this type of system are that for small tanks relatively high accuracy measurement is achievable for a relatively low cost. A further benefit of this type of system is that water, gasoline and pressure can all be measured from just one sensor.

The testing of magnetostrictive systems currently is limited because it is not possible to see the probe since it is entirely contained within the tank. Removal of the probe is not necessarily a trivial matter because the probes can be many metres in length because they span the whole length of the tank.

On the smaller scale fuel forecourt magnetostrictive systems, there are a number of known issues. These include:

- Floats getting stuck;
- Probe getting bent during installation. This will be a prominent issue for larger storage tanks because the probe has to be the same height as the tank. Therefore one of the major drawbacks currently with using this method of level measurement is the difficulty of the initial installation, especially in above ground tanks.

[32] *http://www.sensorsmag.com/sensors/leak-level/a-dozen-ways-measure-fluid-level-and-how-they-work-1067, accessed on 7th January 2011*

3.5 TANK INSPECTION[33]

The inspection of a level measurement system used for process control rather than for a safety function, such as overfill prevention, is really the same as any other instrumented or control system. For example, the inspection should look at the following areas:

- The condition of the physical installation of the equipment (transducers, cabling, local equipment room and cabinets) is good.
- What is the calibration regime for the gauges?
- What records exist to show regular calibration?
- Observe a calibration exercise.
- Review status of software maintenance on the data management and display system.

3.6 EFFECT OF TANK DESIGN ON ACCURACY OF MEASUREMENT IN TANKS

A journal article by FJ Berto[34] states that a number of measurement accuracy limitations in the use of manual and automatic tank gauging are presented in the API MPMS (American Petroleum Institute, Manual of Petroleum Measurement Standards). The discussion presented treats the tank gauging system and the tank as the system, not just the instrumentation that performs the measurement. This introduces the idea of designing both components to be 'as one' in the same way, with a view to minimising factors from each that can affect accuracy. The limitations stated in API MPMS are:

- Accuracy of the manual gauging tape or ATG;
- Accuracy of the tank capacity table and the effect of tank tilt and hydrostatic pressure;
- Shell expansion caused by the material contained;
- Under-measurement as a result of the tank bottom shifting under load from its perceived position;
- Movement of the gauging well. Excessive movement in the gauging well reduces capability for accurate level measurement. Guidance should be sought to install the gauging well to minimise any potential for gauging well movement;
- Volume measurement accuracy is affected by movement of the tanks datum plate;
- Over-measurement can occur when heavy or waxy materials leave a solidified residue, known as encrustation;
- Thermal effects such as expansion or contraction of the tank. For level-based measurement, as opposed to volume measurement, this can have a significant impact because an expanded tank may contain a greater volume of fuel at a specific mid-point than it would at the same mid point when not expanded;
- Human error. These are normally associated more with manual means of level measurement, and less so with ATG.

Berto's article highlights that the accuracy of any method of level measurement or tank gauging can be significantly affected by the tank. Considerations such as the expansion and contraction of the tank under loading, how the bottom moves under load, and reaction to changes in temperature can all affect the dimensions of the tank. The tank gauging system should be installed bearing in mind these physical factors of the tank, and where possible designing the installation to minimise the effects upon measurement by the tank.

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[33] *Griffiths P. Private communication 11th May 2010*

[34] *Berto FJ (1997). Review of Tank Measurement Errors Reveals Techniques for Greater Accuracy. Oil and Gas Journal 1997, Volume 95, Issue 9, pp68-73*

4 TANK LEVEL DETECTION SWITCHES

Switches are associated more with alarm initiation and executive response initiation. Unlike the monitoring systems, switches do not give continuous level measurement but are used to alert. Appendix 4 of the PSLG report 'Guidance on automatic overfill protection systems for bulk gasoline storage tanks' states in paragraph 7, bullet 1, 'Analogue level sensors are preferred to digital switched sensors'.

Magnetic level switches, conductivity and field-effect level switches, and microwave level switches are established level measurement switches. However they are not appropriate for fuel storage application and therefore outside of the scope of this report. Appendix 4 gives a summary table of types of limit switches that can be used in the fuel storage industry.

4.1 VIBRATION SWITCH

This type of switch, also known as a 'tuning fork switch', uses piezo crystals that continually resonate at a known frequency in open air. The rate at which these crystals resonate is affected when it is immersed in liquid. The principle adopted for this type of switch in tank level overfill prevention is that the piezo crystal is harnessed to two metal prongs which come into contact with the stored gasoline in the tank as the tank level alters. When the prongs, which are resonating due to the piezo crystal connection, come into contact with the gasoline, the frequency at which the prongs resonate changes. If the detected oscillation varies greatly from the crystal's natural oscillation frequency, its resonant frequency (accounting for attenuation factors), it is implied that the crystal is exposed to an atmosphere other than air, namely gasoline, and the switch signal activates.

4.2 DISPLACER (LIMIT) SWITCH

Displacer switches work by using a spring-loaded weight, known as a displacer, which is held by its own weight on the surface of the liquid in the tank. As the level of the liquid rises, a steel armature which the displacer is attached to rises into the mechanical switch mechanism. This armature passes a magnet that activates the switch. When the liquid level in the tank reduces, resulting in the displacers lowering, the switching action is reversed[35].

4.3 MECHANICAL (LIMIT) SWITCH

Mechanical switches use a form of lever (plungers and wobble sticks are also used) which moves according to the level of the liquid within the tank. When the liquid reaches a certain level, the motion of the moving lever contacts the switch. When the level moves away from the activating level, the positioning of the lever causes the contacts of the switch to break apart.

Mechanical switches are continuously operational because they do not rely on any factors other than the level of liquid within the tank.

4.4 OPTICAL LEVEL SWITCH

A light source and detector are used to determine the presence of liquid in a storage tank. This non-intrusive method shines a light source onto the surface of the liquid. The reflection is then detected. Examples of light sources are light emitting diodes (LED) or lasers. This type of switch requires the detector lenses to be cleaned regularly, therefore these switches can have a significant inspection and maintenance overhead.

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[35] *www.bdssystems.com accessed on 21st July 2010*

4.5 MAGNETIC REED SWITCH

A magnetic reed switch allows or blocks electrical current flow by the magnetisation of two metal strips 'reeds'. The presence of a magnetic field, which is provided by a magnetic float within the tank, draws the two reeds together allowing current flow through the circuit. When the magnetic float moves away from the reed switch, the magnetic field is removed and they separate. This separation occurs because the stiffness of the reeds forces them back apart. The reeds are normally housed in a glass hermetically sealed tube that attempts to protect them against corrosion due to moisture or aggressive materials.

4.6 NOVEL TANK LEVEL SWITCHING METHOD

The American Petroleum Institute (API) has presented a method of overfill detection for fuel storage tanks that uses instrumentation external to the tank. This method has been successfully implemented by a reputable fuel storage facility in America[36]. This system uses three pipes that run parallel to the outside of the fuel storage tank. Of these pipes, the centre one is tapped into the bottom of the tank and always has liquid fuel present inside. This pipe is also vented to atmosphere so that it can be assumed that the level in the pipe is the same as the level within the tank. The two outer side pipes are connected to the centre pipe at high and/or high-high level alarm points. These connections are piped connections between the centre pipe and the outer pipes, which will allow liquid flow from the centre pipe to the outer pipe when the fuel level reaches alarm activation point, i.e. the connection pipe point. In the case where fuel overspills into the outer pipes, an alarm activates when the fuel begins to accumulate in the bottom of the pipe. This method presents many advantages over currently adopted level switching methods because it is non-invasive to the tank, and alarm sensors are only exposed to fuel when an alarm event occurs. However the centre pipe that continually contains fuel must be protected from external damage, because if this pipe were to fracture it could become a cause of loss of containment of tank contents.

4.7 PROBLEMS WITH PROOF TESTING HI-HI LEVEL SWITCHES

An HSE Control & Instrumentation inspector has stated that the most common type of hi-hi level switch used is the magnetic reed type. Proof testing without full knowledge of the switch mechanism has proved unsatisfactory at Buncefield. One of the greatest shortcomings in the testing of hi-hi level switches is the lack of proper training of technicians or correct effective written procedures for proof tests. It is thought that this would have contributed to eliminating the weakness in the Buncefield regime. Other problems encountered in proof testing hi-hi level switches can be aspects such as detaching of the float which the switch is connected to, 'lock-up' where the float belonging to the switch becomes lodged within the stilling well, or even a physical failure of the switch due to wear or manufacture defect.

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[36] *Brown S and Pearson J (2007). RE: Overfill tubes, Private communication. 10th May 2007*

5 GAS DETECTION METHODS[37]

MIIB recommendation 13 is concerned with the detection of gas lost from primary containment. This section briefly discusses gas and vapour detection methods that can be used on fuel storage tanks. It should be noted that leak detection is not a primary focus of this report and therefore is not discussed. However HSL report ECM/2008/08 'A review of leak detection for fuel storage sites' by P Walsh and A Kelsey highlights the considerations that are to be given to gas detection systems that are to be used on a gasoline storage site. This report is available to the public at http://www.firedirect.net/Technical/HSELeakDetection.pdf, which discusses gas and liquid detectors that can be used on Buncefield-type fuel storage sites.

5.1 DISTRIBUTED GAS DETECTION SYSTEM[38]

These systems work by having a number of gas detection sensors placed around the fuel storage tank. The sensors are continually feeding back gas level information to a central processor that is comparing all the measurements. In the event of a gas measurement being substantially higher than the others, an alarm is raised. This method of detection can be constructed using off the shelf components. Alternatively there are a number of suppliers that provide this type of system off the shelf. Problems associated with such systems include poisoning of catalytic detectors and the fact they can be affected by weather and, particularly, moisture mist on some detections systems.

5.2 MOBILE GAS DETECTION

Portable combustible gas detectors can be used for identifying fuels in vapour form in areas that it should not be in. Average gas detectors are able to detect gasoline at 1 ppm, and liquid hydrocarbons at 50 ppm.

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[37] *Section 7.9 Leak Detectors. Instrument Liptak BG (2003).* Instrument Engineers' Handbook Process Measurement and Analysis Volume 1, 4th Edition, *CRC Press ISBN 0-8493-1083-0*

[38] *http://www.fuelguard.com/ accessed on 4th January 2010*

6 HSE 2006 SURVEY OF MAIN FUEL STORAGE FACILITIES IN THE UK

In 2006 HSE conducted a survey via questionnaire to the main fuel storage operators in the UK. The purpose of this work was to find out what safety-related instrumentation was used on these sites and how these systems were tested. A table summarising the feedback is presented in Appendix 2, HSE High Level questionnaire feedback summary.

6.1 TEST METHODS

The response to this questionnaire was generally the same for all the operators questioned. The sensor was removed from its operational area and artificially put into an alarm-triggering state. Activation of the alarm was observed and acknowledged in a control/alarm room of the site, followed by the sensor being taken out of alarm state, then being returned back to its operating position. Generally, the testing sequence finishes by alarm reset and recommencing of normal operation. The types of switch that were named in responses to the survey are stated in Table 1 below.

Table 1 Table stating the sensor type and manufacturer named in response to the HSE 2006 survey of fuel storage operators in the UK

Switch/Sensor	Manufacturer(s)
Tuning fork	(Liquiphant) Endress & Hauser
Top mounted liquid displacer level switch	Magnetrol International N.V
Float & weight	TAV
Float	TAV, Mobrey Trist
Displacer	TAV, Alan Cobham Engineering
Magnetic limit switch	Alan Cobham Engineering
Limit switch (normally closed micro switch, opened on rising level)	Whessoe

6.2 FAILURES & LOSS OF CONTAINMENT CAUSES

There are numerous ways in which a gasoline fuel storage tank and its associated level measurement system may fail. Even well-maintained and inspected storage facilities are not immune to failures that lead to loss of containment. This section highlights some possible failure modes that could lead to either loss of containment or ignition of the stored gasoline.

Level measurement system manufacturers suggest to operators of fuel storage facilities that separate failure alarms are installed on level measurement equipment. On modern systems this is made relatively straightforward, because many manufacturers incorporate a facility where an output signal is triggered in the event of a component failure.

Industry experts have suggested that proof testing of level measurement systems can be done in one of two ways:

1. Controlled fill to high level to initiate a controlled alarm activation;
2. Electronically force a trip/alarm activation.

The controlled fill is the proof test method of choice. However they are very aware of the constraints upon industry and how this is very difficult to perform[39]. This goes some way towards identifying tank and system failures as early as possible, but it is by no means a safeguard against failures.

6.2.1 Floating roof failure[40].

The failure of a floating roof on large storage tanks has been stated as being caused by the following:

- Fire or explosion due to hydrocarbon accumulation on roof;
- Roof sinking caused by rain water accumulation;
- Overfilling;
- Leaky pontoon;
- Roof misalignment.

The research paper by N Tzonev et al entitled 'Sensor Systems for monitoring of floating roofs in petroleum storage tanks' discusses the possibility of using wireless sensors for the detection of floating roof failure before total failure occurs.

6.2.2 Causes of explosion

Electrical wire loops can induce potential differences that electrostatically discharge resulting in the ignition of flammable gas accumulation.

6.2.3 Communication systems software[41]

An HSE specialist Control & Instrumentation inspector recalls from his time visiting fuel storage sites that the most commonly encountered software system used was the ENRAF system for bringing information to the control room. The software involved is quite complex and the actual transducers on the tank, whilst vital for accuracy, are not the major part of the installation. The display system provides many complex correction factors based on the strapping tables for the tanks. These enable the depth of liquid to be converted to volume figures, corrected for the varying tank diameter up and down the tanks. There are also facilities for temperature correction. They provide rapid back up to the user sites that typically would not have the expertise to fault find and correct the systems.

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[39] *Meeting with industry specialists. Meeting minutes. 18th November 2010*

[40] *N. Tzonev, D. Sime, T. Darcie (2008) Sensor Systems for Monitoring Of Floating Roofs in Petroleum Storage Tanks. Syscor Controls & Automation Inc. Victoria*

[41] *Griffiths P. Private communication. 11th May 2010*

7 CONCLUSIONS

Many types of tank gauging systems have adequate reliability in gasoline measurement applications, but issues have been raised for biofuels which can be more corrosive. Similar issues could apply for some Buncefield in-scope substances. Dip tapes are still a highly regarded method of level measurement of tank contents despite the scope for measurement inconsistency, and are used in the initial installation and calibration of many automatic tank gauging systems. Dip tapes are used in custody transfer measurements and there is guidance available from HM Revenues and Customs for considerations when using dip tapes for official measurement.

The main types of tank level detection used in the gasoline storage industry are:

- Servo-operated float gauges;
- Radar tank gauges (both contacting and non-contacting);
- Air bubbler;
- Surface detector (plumb-bob) gauges;
- Float-operated, wire-guided, inductively coupled gauges.

Servo-operated float and radar tank gauges are currently the most commonly encountered level measurement systems used on gasoline storage sites. Gasoline does not have a major detrimental effect on servo-operated float gauge systems so long as care is taken to ensure that suitable materials are used for seals and gaskets. However, the same cannot be said of the effect of bio-fuels. Due to some corrosive bio-fuel additives, these gauges can be damaged. This can be problematic because some tanks may be used to store both bio-fuel and gasoline at different points in their service life. This changeover may not be captured in a company's management of change procedures and as such may not be subject to impact analysis or risk assessment.

The main types of level switches are:

- Vibration switch;
- Displacer (limit) switch;
- Mechanical (limit) switch;
- Optical level switch;
- Magnetic reed switch.

The most commonly encountered level switches on gasoline storage sites are magnetic reed switches for hi-hi level detection and alarm initiation.

Gas detection was briefly discussed because MIIB recommendation 13 is concerned with the detection of gas lost from primary containment. 'A review of leak detection for fuel storage sites' by P Walsh and A Kelsey of the Health and Safety Laboratory discusses in more detail gas detection systems used on gasoline storage sites. This report is available to the public from http://www.firedirect.net/Technical/HSELeakDetection.pdf.

With the evolution of manufacturing techniques it is possible to produce magnetostrictive level measurement components on a physically larger scale. Up until recently they were not viable measurement methods at fuel storage facilities despite being highly accurate and used for custody transfer on filling station forecourts. Manufacturers of level measurement systems are now beginning to develop and market 'hybrid' measurement systems. Examples of these are hydrostatic tank gauging (HTG) systems that use smart sensors, and a system that encapsulates radar and capacitive tank gauging technology.

APPENDICES

APPENDIX 1 QUESTIONNAIRE SENT TO TANK GAUGING SYSTEM TECHNICAL EXPERTS FOR THE PURPOSE OF INFORMATION GATHERING

Fundamental questions posed to technical experts in the field of level measurement systems

1. Dip tapes. How is this method of tank gauging traditionally performed? Is there a definitive method that is or should be adopted when measuring?
2. What is the most commonly adopted tank gauging system used on fuel storage sites and why are these systems chosen over other systems?
3. What are common problems encountered in the day-to-day running and maintenance of tank gauging systems used for fuel storage applications?
4. What are the key points that should be considered when inspecting a tank gauging system?
5. Do you have any examples from your experiences as an inspector of novel applications of instrumentation being used for measuring levels of liquid within a tank?
6. Do you have any examples from your experiences as an inspector of level measurement of liquid in tanks not operating correctly when they were assumed to be? What was the shortcoming and how did the dutyholder address it?

Body of the email sent to members of HSE, HID CI2E

I am writing to ask if it would be possible for you to take a small amount of time out of your busy schedules to take part in a small research project on the subject of tank gauging for 'Buncefield in-scope substances'.

Jeff Pearson has commissioned us to produce a report, which highlights the main types of tank gauging systems used on Buncefield type fuel storage sites in the UK. The work is being undertaken in two stages:

- Stage 1. Identify current tank gauging systems used in fuel storage application and highlight benefits, failure modes, common faults and fitness for purpose of each.
- Stage 2. Identify emerging technologies and methods for tank gauging. For the systems found further research will be performed to determine how they are superior to existing systems and why they might be chosen.

The outcome of this work will be a report that can be used as a quick reference guide.

We would like to draw upon your experiences and knowledge from your time as inspectors to fill in our knowledge gaps of commonly applied tank-gauging systems for fuel storage applications. Attached are two Excel spreadsheets:

- Tank gauging systems commonly used in fuel storage applications,
- Switches used in tank gauging systems for fuel storage applications.

We have populated these tables so far using information from literature reviews and net searches. If you have further knowledge on any of the stated systems or switches please let us know and we can update our tables, especially in cases where we have not entered any information.

APPENDIX 2 HSE HIGH LEVEL QUESTIONNAIRE FEEDBACK SUMMARY

Site	Switch Type	Manufacturer	Dangerous Unrevealed failure modes	Interval (yr)	Coverage (%)	PFD	Test Method	Model Information
A	Tuning Fork	Endress & Hauser	110 fits (Failure In Time. 1 FIT = 1*10-9)	1		<0.03* 10-2	1. Open tank valve to mimic import 2. Remove switch from tank roof 3. Immerse tuning fork in liquid and confirm valve closure 4. Replace tuning folk switch on tank roof 5. End of Test	
	Top mounted liquid displacer level switch	Magnetrol International N.V.	95.25 fits	1	95.16	0.0004 17		
B	Tuning Fork	Endress & Hauser	1 in 55 years	1	13.5 months		1. Open tank valve to mimic import 2. Remove switch from tank roof 3. Immerse tuning fork in liquid and confirm valve closure 4. Replace tuning folk switch on tank roof 5. End of Test	
	Float & Weight	TAV	No Data	1	No data	No data	Weight Test 1. Remove switch from tank top 2. Lower weight onto tank top to release wire tension. This simulates raising of IFD 3. Observe that alarm is raised 4. Put switch back in tank 5. End of Test Float Test 1. Same as weight test but is lowered into water slowly until wire tension released. This simulates increasing liquid level.	
C	Top mounted liquid displacer level switch	Magnetrol International N.V.	95.25	0.5	95.16	4.17E-04		A15-AK3L-CH9
D	Displacer	Alan Cobham Engineering	None	0.08333	100	No data	Monthly Test 1. Open import valves by opening the test lever. 2. Check HH level alarm is activated in control room. 3. Close import valves and replace locking padlock. 4. Reset alarms. 5. End of Test	Flameproof model FS4320
E	Float	TAV	None	0.08333	100	No data	Monthly Test 1. Open import valves by opening the test lever. 2. Check HH level alarm is activated in control room. 3. Close import valves and replace locking padlock. 4. Reset alarms. 5. End of Test	Model F150. See HSE issued note post Buncefield

	Float	TAV	None	0.08333	100	No data	Monthly Test 1. Open import valves by opening the test lever. 2. Check HH level alarm is activated in control room. 3. Close import valves and replace locking padlock. 4. Reset alarms. 5. End of Test	Model F160. See HSE issued note post Buncefield
F	Float	Cobham	1. Cable short cct. 2. Switch welded contacts or mechanically seized 3. Float detaches from arm, build up of foreign bodies seizing arm connection, float punctured/corroded	0.5	Dry only	No data	1. Handle unscrewed and test wires pulled until stop is reached. 2. Alarm is observed activating in control room 3. Test wires lowered back to service position and handle screwed back into position. 4. Alarm reset. 5. End of Test	
G	magnetic limit switch	Cobham	1. Cable fault - open/short/earth 2. Switch malfunction - switch welded contacts or mechanically seized 3. Failure of annunciation cct/relay/lamp/logic system 4. loop power/fuse 5. Pole becomes bent or detaches from tank	0.5	Dry only	No data	1. Metal tube is lifted over reed switch to the high level position. 2. Alarm is observed activating in control room 3. The tube is lowered back into normal operating position. 4. Alarm reset. 5. End of Test	
	Float Arm	Mobrey Trist	1. Cable fault - open/short/earth 2. Switch malfunction - switch welded contacts or mechanically seized 3. Failure of annunciation cct/relay/lamp/logic system 4. loop power/fuse 5. Float detaches from arm, build up of foreign bodies seizing arm connection, float punctured/corroded	0.16667	Dry only	No failure in last 6 years	1. Test wire hauser is pulled or rod up. 2. Alarm is observed activating in control room 3. The test wire hauser is lowered or rod down back to operating position. 4. Alarm reset. 5. End of Test	
	Limit Switch (normally closed micro switch, opened on rising level)	Whessoe	1. Cable fault - open/short/earth 2. Switch malfunction - switch welded contacts or mechanically seized 3. Failure of annunciation cct/relay/lamp/logic system 4. loop power/fuse 5. Pole becomes bent or detached from tank	0.5	Dry only	No data	1. cam on rotary limit switch is moved to the high level position. 2. Alarm is observed activating in control room 3. Cam moved back to the normal operating position. 4. Alarm reset. 5. End of Test	

	Limit Switch (normally closed micro switch, opened on rising level)	Whessoe	1. Cable fault - open/short/earth 2. Switch malfunction - switch welded contacts or mechanically seized 3. Failure of annunciation cct/relay/lamp/logic system 4. loop power/fuse 5. Pole becomes bent or detached from tank	0.16667	Dry only	2 failures in 7 years	1. Raise pole to strike the rotary switch. 2. Alarm is observed activating in control room 3. Lower pole to normal operating position. 4. Alarm reset. 5. End of Test	
	Displacer	TAV	1. Cable short cct. 2. Switch welded contacts or mechanically seized 3. Test leaver locked or left in down position	0.16667	Dry only	No data	1. Unlock test leaver and raise weight. 2. Alarm is observed activating in control room 3. Lower leaver/weight back down to operational normal operating position. Lock in position. 4. Alarm reset. 5. End of Test	Checkable displacer
	Float	TAV	1. Cable short cct. 2. Switch welded contacts or mechanically seized 3. Test leaver locked or left in down position 4. Float detaches from arm, build up of foreign bodies seizing arm connection, float punctured / corroded.	0.16667	Dry only	No data	1. Unlock test leaver and raise float. 2. Alarm is observed activating in control room 3. Lower leaver/weight back down to operational normal operating position. Lock in position. 4. Alarm reset. 5. End of Test	Float on vertical stem with facility to lift float for checking. Magnetic coupled arm/switch. Normally closed micro-switch.

APPENDIX 3 QUESTION SET PREPARED TO POSE TO INDUSTRIAL EXPERTS

These questions aim to find out as much detailed information as possible without necessarily getting product specific information.

Approvals of Systems and Components

1. What test houses in the UK are accepted as reputable in testing and certifying systems and components? Are there any test houses that you would not use or recommend?

2. Where can approved systems and components be obtained from?

3. Who issues certificates once a system is approved?

4. What kind of equipment is generally certified on level measurement systems?

5. Does the additional cost of using certified system components justify the additional cost to the end user? (personal opinion)

6. Is using approved systems common place in the UK?

Popular Systems and Methods Currently Used in Industry

7. What tank gauging system is generally used in the fuel storage industry and what proportion of industry use them?

8. Have you come across sites that use non standard level measurement systems or methods? In cases where you have, why are such systems chosen and what benefits do the sites gain by using them over the common alternatives?

9. ***Ask if no answer to 8.*** New and upcoming technologies. Considering the known limitations of the existing level measurement methods used in industry what action is being taken, either by site owners or system manufacturers, to address these long standing issues?

10. In general terms what type of tank gauging system is generally seen as being the most expensive? Is the extra investment worth the benefit provided? Is there extra cost associated with the maintenance and up keep of the more expensive systems?

Tank Gauging System Failure

11. From your experience what is the most common failure modes of a typical tank gauging system installation? Why is this failure mode so common?

12. Common failure modes experienced. ***(Link to questions 8&9)***. What action is taken by sites, consultancies, or manufacturers to address common failures experienced by tank gauging systems? How do the solutions address the highlighted failures and why is this solution deemed to be the best one?

Tank Gauging System Evolution

13. In your opinion what is the greatest limiting factor in the fuel storage industry and how does this affect the usability of the tank gauging system?

14. What “next generation” systems (either up coming or concept) do you see as furthering the efficiency of tank gauging systems?

APPENDIX 4 OVERVIEW REFERENCE MATERIAL FOR TANK GAUGING SYSTEMS AND TANK GAUGING SWITCHES

Limit Switching Overview

HSL Report Ref	System type	Method	Known issues	Operating temperature (Deg C)		Error in measurement	Comments
				Min	*Max*		
4.1	**Vibration switch**	This type of switch uses piezo crystals, which continually resonate at a known frequency in open air. The rate at which these crystals resonate is affected when it is immersed in liquid The principle adopted for this type of switch in tank level overfill prevention is that the piezo crystal is harnessed in someway to an interacting media which can come into contact with the contained liquid without suffering degradation, and that can conduct the crystals' resonations into the tank containment area. This is the transmit Tx part of the switch. A receive component of the switch Rx listens for the transmitted crystal oscillation. If the received oscillation varies greatly from the crystals' natural oscillation, its resonant frequency (accounting for attenuation factors due to the interacting media), it is implied that the crystal is exposed to an atmosphere other than air, such as the tank liquid, and the switch signal activates	Switch can stop operating if the liquid rises above the probe	-10	80	Up to +/- 3 mm inaccuracy	Material build up on the probe rarely occurs because the probe 'forks' are in constant oscillation

4.2	**Displacer (limit) switch**	Using a spring-loaded weight, known as a displacer, which is held by its own weight on the surface of the liquid in the tank. As the level of the liquid raises a steel armature which the displacer is attached to rises into the mechanical switch mechanism. This armature passes a magnet which activates the switch. When the liquid level in the tank reduces, resulting in the displacers lowering, the switching action is reversed		0	400	up to +/- 5%	
4.3	**Mechanical (limit) switch**	This type of switch is designed to be purely mechanical. This switch uses a form of leaver (plungers and wobble sticks are also used) which move according to the level of the liquid within the tank. When the liquid in the tank reaches a certain level, the motion of the moving leaver contacts the switch. When the level moves away from the activating level, the positioning of the leaver causes the contacts of the switch to break apart Mechanical switches are continuously operational because they do not rely on any factors other than the level of liquid within the tank	Prone to mechanical wear and corrosion due to exposure to some stored materials	-50	150	up to +/- 5%	Oldest type of limit switch. Purely mechanical with no requirement for electrical connection
4.4	**Optical level switch**	A light source and detector are used to determine the presence of liquid in a storage tank. The non-intrusive method shines the light source onto the surface of the liquid. The reflection is then detected. Invasive method shines the light source into the liquid		-40	125	up to +/- 1 mm	

4.5	**Magnetic reed switch**	Uses a switch and magnet encased in a metal attractor sleeve. The sleeve moves up and down according to the level of the tank contents. When the liquid levels becomes too high or too low the sleeve passes over to the magnetic area of the switch which contacts contractors, thus activating the switch	This can pose a possible source of ignition in flammable atmospheres because of the metallic moving parts	0	400	up to +/- 5 mm	

Level measurement systems overview

HSL report Ref	System Type	Method	Known Issues	Uses	Invasive to container	Operating Temperature (Deg C)		Accuracy	Comments	Maintenance
						Min	*Max*			
3.3.1	**Dip tape**	A calibrated tape with an attached weight is lowered into the tank until the weight makes contact with the bottom of the tank. The operator then retracts the tape, whilst carefully noting the graduation on the tape where it ceases to be dry, and comes out of the tank wet. This provides a depth measurement in mm or inches. With known tank dimensions the volume of the liquid present can be calculated	The accuracy achievable is greatly dependant upon the experience and skill of the operator	This is a good 'rough guide' measurement. However it should not be assured to be highly accurate and only be used as a double check	invasive	-40	150	Potential to achieve ± 10 mm	Used in the set up of automated systems such as radar and servo level systems	The tape should be calibrated and should be inspected prior to use for edge fraying
3.3.2	**Float-operated, wire-guided, inductively coupled**	The wire is fixed at both the top and bottom of the tank, and is used as a guide for the float. The float contains an inductively coupled transducer, which the wire provides power to. At short intervals the primary coupling is interrupted, and the secondary inductive coupling from the transducer to the conductor is on the wire is achieved. Measurement is achieved by located conductors at known intervals on the wire, which produces a grey coded word	1. Can experience tape hang ups 2. Material build-up can hinder free movement of the float (cannot be used in dirty applications)	1. 'Clean' measuring applications 2. Custody transfer level measurement	Invasive	-40	260	Low accuracy	One of the cheaper level measurement systems available and are still commonly used	**A high** level of maintenance required because of number of moving parts
3.3.3	**Servo-operated float type**	Works using fluid displacement for continual measurement. A displacer is continually measured within the tank. As the level changes the system always aims to maintain the displacer in equilibrium, which produces the level measurement	1. Cannot be used in dirty applications 2. Ferrous materials can adversely affect the operation of the system	1. Custody Transfer 2. Inventory Management 3. Measurement of Problematic Petrochemicals	Invasive	-40	200	Up to +/- 5 mm	Currently this is one of the most popular level measurement methods used in gasoline storage in the UK	A **high** level of maintenance required because of number of moving parts
3.3.4	**Plumb bob**	A 'plumb line' weight is lowered from the sensor unit, which is fixed to the top of the tank, until the weight makes contact with the surface of the contained material. The weight is then retracted into the sensor unit whilst the line is measured. The resulting measurement is then used to calculate the level of material present in the tank	Plumb weight can become jammed in the sensor unit	Periodic level measurement only	invasive	-40	150	Dependent upon maintenance Not comparable to servo or radar level measurement	It is suggested by industry experts that both the system designers and manufacturers consider this method of tank gauging should no longer be used because of the varying levels of reliability and accuracy of measurement and the methods high maintenance demands	A **high** level of maintenance required because of number of moving parts
3.3.5	**Radiation backscatter design**	Uses radioactive source as transmitter and a radiation detector to determine the level of material within the containing vessel	Very expensive	Preferential system of measurement for highly corrosive materials which would degrade the quality of measurement of other level measurement systems	Non-invasive	Not affected by temperature		Highly accurate	This technology is not commonly seen in the UK gasoline storage industry. Although very accurate, comparable accuracy can be achieved with radar or servo gauges, both of which carry a lower maintenance and inspection overhead	Maintenance requirements of this system are low compared to mechanical alternatives. However there may be other inspection obligations associated with radioactive source licensing

3.3.6	**Radar tank gauges (Non-contacting)**	Uses K or X band electromagnetic waves for continuous monitoring of the level. Communication is by means of Frequency Modulation Carrier Wave (FMCW). Pulse width modulation is also used by some variants of this system	Can experience interference from process equipment, vessel agitators etc	1. Inventory Control 2. Process Control 3. Custody Transfer	Non-invasive	-60	400	Very accurate but easily affected by external interference. Up to +/- 3 mm	Replaces many systems that use to be ultrasonic or radiation source based systems Currently this is one of the most popular level measurement methods used in gasoline storage in the UK Can be used in numerous environments, intrinsically safe, explosion proof, non-incendive (electrical, but are not able to cause ignition)	Maintenance requirements are low compared to mechanical alternatives because there are far less moving parts. However electronic equipment requires inspection to ensure component aging does not degrade measurements
3.3.6	**Radar tank gauges (Contacting)**	This method has a probe, known commonly as a 'waveguide', situated in the container which is used to perform the measurement by transmitting a periodic pulse. A number of different receiving method now exist which sense for a reflected signal. The currently used and accepted methods are:1. Time Domain Reflectometry (TDR). *Newer higher efficiency low power, DC sensing methods are also available. These are:*2. Guided wave radar (GWR). *Based upon TDR* 3. Phase Difference Sensor (PDS). *Determines level from change in phase angle of material in container*	Can only accurately provide level measurements in materials with dielectric values greater than 1.4 (I.e. will not work well with water based materials)	1. Inventory Control 2. Process Control 3. Custody Transfer	Invasive	-200	400	Accuracy is dependant upon the dielectric constant (material permittivity). Up to +/- 2 mm		Maintenance requirements are low compared to mechanical alternatives because there are far less moving parts. However electronic equipment requires inspection to ensure component aging does not degrade measurements
3.3.7	**Capacitive level measurement**	A capacitor configuration is made up, using the sensor probe and the metal tank wall as capacitor plates. The material contained within the tank will enter the area between the two 'plates' and cause the measured capacitance to vary as the level in the tank changes	It is not possible to measure the point at which stored material changes. For example gasoline water boundary cannot be determined	1. Inventory Control 2. Process Control 3. Custody Transfer	invasive	-80	200	1% of measuring distance	A manufacturer has developed a new generation level measurement system that utilises capacitance and radar level measurement technologies	Maintenance requirements are low compared to mechanical alternatives because there are far less moving parts. However electronic equipment requires inspection to ensure component aging does not degrade measurements
3.3.8	**Hydrostatic tank gauges (HTGs)**	Works by placing of pressure sensors at various points of the tank. These pressure readings are then used in the calculation of the mass of material in the tank. HTC can be implemented using one pressure difference sensor which compensates for measurement errors which can be introduced when using two individual sensors	Placement of sensors can lead to error introduction which can in turn lead to inaccurate level measurement	1. Clean liquid measurement (atmospheric & pressurised) 2. Hard to handle fluid measurement (atmospheric & pressurised) 3. Bi-phase material 4. Cryogenic material 5. Boiling material	Non-invasive	-70	350	Low accuracy using single pressure sensor Highly accurate when **two or more** pressure sensors used	This is a form of differential tank gauging	In theory maintenance would not be required on these systems. However in reality inspection and replacement of pressure and temperature sensors will be required. At the very least removal of material deposits from sensor surface would be required
3.3.9	**Ultrasonic tank gauging**	The sensor emits an acoustic frequency between 20kHz and 200kHz. This emission is then reflected back from the liquid surface towards a detector. The time taken between transmitting a signal and receiving the reflected signal give the measure of the liquid level in the tank	accuracy of measurement is effected by positioning of the ultrasonic transducer This type of measurement system is susceptible to ringing	This method of level measurement is rarely used in the gasoline storage industry, mainly because of its perceived inaccuracy	invasive	-40	150	Low	This is not commonly seen in the UK gasoline storage industry. It is more popular in the water industry	Maintenance regime would be similar to that required for radar based systems

3.3.10	**Air bubbler level measurement**	A fixed rate of air passes through a tube that is submerged in the liquid. Some of the air escapes through the outlet of the tube. The pressure in the tube is proportional to the depth and density of the liquid over the outlet of tube	Not considered to be accurate enough for custody transfer Requires specialist knowledge for maintenance	Used on open tanks at atmospheric pressure	invasive	0	60	Up to +/- 10 mm of level	An advantage with this method is that it is possible to site the control and instrumentation equipment away from the physical storage tanks, which removes some or in case all of the requirements for equipment to be Ex rated	Maintenance activity requires specialist operatives
3.3.11	**Hybrid tank gauges**	Similar to HTG systems	Unknown	Can measure volume, mass temperature and density in certain configurations	Non-invasive	???	???	Unknown	This form of tank gauging is still evolving. As such further research into principles surrounding it should follow	Unknown
3.3.12	**Thermal differential**	This method uses thermal differential monitoring via two RTDs. One RTD measures liquid temperature in its immediate vicinity. The second RTD is self heating and raises to a predefined temperature. Comparing the temperatures read provides a differential. Using knowledge of thermal characteristics of the liquid, it can be determined if liquid is present at the sensor point in the tank. If the differential is outside of the expected range it is assumed that the RTD sensing is in gas, not in liquid, hence a level detection	This type of measurement system cannot be used when the introduction of heat to the stored product would cause its degradation or compromise its chemical stability	1. To determine if tank level is below threshold 2. Monitor flow of liquid to or from tank vessels	invasive	-70	350	Can achieve between 0.1% and 5% of the full scale measurement	This is not a commonly used level measurement method in the gasoline storage industry	Maintenance regime would be similar to that required for radar based systems because of the lack of moving parts
3.3.13	**Slip tube gauging**	Rotary method. A head is used to extract the contents of the tank vessel. The head operates until vapour is discharged from the bleed connection. When the vapour is detected a handle is turned which rotates the slip tube assembly. This continues until liquid begins to discharge from the slip tube Vertical Method. The slip tube is lowered into the tank vessel. Once in contact, the liquid will start to bleed out of the cap assembly instead of vapour. The level that the liquid reaches in the tube can correlate to the level in the tank	This measurement method requires a quantity of the stored material to be lost to atmosphere. With gasoline such a measurement would raise environmental issues	This method of level measurement is rarely used in the gasoline storage industry	invasive	10	45	Not quantified, but considered highly inaccurate	The widely held view through the fuel storage industry and system installers is that this is not a suitable level measurement method for gasoline storage tanks	Unknown

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Health and Safety Executive

Identification of instrumented level detection and measurement systems used with Buncefield in-scope substances

The Major Incident Investigation Board (MIIB) was formed to investigate the Buncefield incident of December 2005. Its purpose was to make recommendations to help ensure that this kind of incident does not occur again in the future. The MIIB made a number of recommendations associated with the design and operation of Buncefield in-scope fuel storage tanks. This work considers MIIB Recommendations 8 and 13 stated in both 'The Buncefield Incident 11 December 2005, The final report of the Major Incident Investigation Board Volume 2' and in 'Safety and environmental standards for fuel storage sites, Process Safety Leadership Group, Final Report'.

The purpose of this report is to present the current methods and technologies used by industry for implementing tank gauging systems. The report will focus on tank gauging systems and level detection systems that can be implemented for 'in-scope Buncefield substances' storage facilities.

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