Hydrocarbon process single and multi-layer level measurement – Recommended Practice
Acknowledgements

IOGP Instrumentation and Automaton Standards Subcommittee (IASSC)
Level Measurement Task Force:

BG Group  PETRONAS Carigali Sdn Bhd
BP  Repsol
Endress + Hauser  Siemens
Emerson  Statoil
Honeywell  Total
Krohne  Vega
Petrobras  Yokogawa

Photography used with permission courtesy of © michaelmjc/iStockphoto and © ThomasVogel/iStock (Front cover)
© William Fawcett fotoVoyager.com (Back cover)

Disclaimer

Whilst every effort has been made to ensure the accuracy of the information contained in this publication, neither IOGP nor any of its Members past present or future warrants its accuracy or will, regardless of its or their negligence, assume liability for any foreseeable or unforeseeable use made thereof, which liability is hereby excluded. Consequently, such use is at the recipient’s own risk on the basis that any use by the recipient constitutes agreement to the terms of this disclaimer. The recipient is obliged to inform any subsequent recipient of such terms.

This publication is made available for information purposes and solely for the private use of the user. IOGP will not directly or indirectly endorse, approve or accredit the content of any course, event or otherwise where this publication will be reproduced.

Copyright notice

The contents of these pages are © International Association of Oil & Gas Producers. Permission is given to reproduce this report in whole or in part provided (i) that the copyright of IOGP and (ii) the sources are acknowledged. All other rights are reserved. Any other use requires the prior written permission of IOGP.

These Terms and Conditions shall be governed by and construed in accordance with the laws of England and Wales. Disputes arising here from shall be exclusively subject to the jurisdiction of the courts of England and Wales.
Hydrocarbon process single and multi-layer level measurement – Recommended Practice

Revision history

<table>
<thead>
<tr>
<th>VERSION</th>
<th>DATE</th>
<th>AMENDMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>December 2015</td>
<td>First release</td>
</tr>
</tbody>
</table>
Table of Contents

1. Introduction 6
   1.1 Objectives 6
   1.2 Scope 6
   1.3 Reference documents 7
   1.4 Abbreviations 8

2. General 9
   2.1 Pressure vessel connection 9
   2.2 Vessel bottom connection 10
   2.3 Range selection 10
   2.4 Material 11
   2.5 Environment 11
   2.6 Standpipes vs. sensor cages 11
   2.7 Level sketches 12
   2.8 Data 12
   2.9 Emulsion 13
   2.10 Calibration 14
   2.11 Stilling wells 15
   2.12 Centring disk 15
   2.13 Control and safety 15
   2.14 Heat tracing 16
   2.15 Maintenance access 16
   2.16 Service capabilities 17

3. Differential pressure transmitter 18
   3.1 Measurement principle 18
   3.2 Limitations 19
   3.3 Selection 19
   3.4 Design 22
   3.5 Installation 26
   3.6 Calibration and configuration 27

4. Displacer (buoyancy) 28
   4.1 Measurement principle 28
   4.2 Limitations 29
   4.3 Selection 29
   4.4 Design 30
   4.5 Installation 30
   4.6 Calibration and configuration 30

5. Ultrasonic 32
5.1 Measurement principle 32
5.2 Limitations 32
5.3 Selection 32
5.4 Design 32
5.5 Installation 33
5.6 Calibration and configuration 34

6. Capacitance 35
6.1 Measurement principle 35
6.2 Limitations 36
6.3 Selection 37
6.4 Design 37
6.5 Installation 38
6.6 Calibration and configuration 38

7. Non-contact radar 40
7.1 Measurement principle 40
7.2 Limitations 42
7.3 Selection 44
7.4 Design 45
7.5 Installation 46
7.6 Calibration and configuration 49

8. Guided wave radar 50
8.1 Measurement principle 50
8.2 Limitations 51
8.3 Selection 55
8.4 Installation 55
8.5 Calibration and configuration 62

9. Hybrid capacitance/GWR 63
9.1 Measurement principle 63
9.2 Limitations 64
9.3 Selection 64
9.4 Design 64
9.5 Installation 65
9.6 Calibration and configuration for interface level measurement 65

10. Nucleonic 66
10.1 Measurement principle 66
10.2 Limitations 68
10.3 Selection 69
10.4 Design 69
1. Introduction

Measurement of single and multi-layer level in the hydrocarbon processing industries is commonly needed, but doing so accurately is often challenging. There are a great diversity of situations which require such level measurement, ranging from pure fluid to viscous, muggy and corrosive fluids.

The environment for these level sensors varies from vacuum to high pressure and from low to high temperature. To deal with these varied situations and environments, many types of sensors, employing a variety of measurement techniques, have been developed.

These include, for example, externally mounted displacers, differential pressure transmitters, guided wave radar, ultrasonic transducers, single-electrode and multi-electrode capacitance sensors. The methods used in the hydrocarbon process for measuring the single and multi-layer are limited because of the request on high reliability, variety of fluids and harsh environments.

1.1 Objectives

The objectives of this IOGP Recommended Practice (RP) are to:

- provide upstream oil and gas industry guidance in the provision of level measurement from an instrumentation perspective
- be in the form of an IOGP format that is publically available
- not contradict any existing IEC/ISO/API standards, but to provide further clarification on the commonly used technologies used in the context of upstream oil and gas
- make it easier for Product Manufacturer and Asset Owners to deliver level measurement devices proven in use and suitable for specific applications.

1.2 Scope

This RP covers the selection and installation of instruments used for single and multi-layer level measurement that are encountered in upstream hydrocarbon facilities.

This includes the overall and interface hydrocarbon process level measurement for liquids, recognizing the need to cater for emulsion and foaming issues.

Excluded from scope: LNG (including Tank Gauging), cryogenic and refrigerated storage, legal metrology (i.e. fiscal or custody transfer) or solid (pellet or sulphur silos, coke chambers, etc.) applications.

Notes

1. This document includes the identification of the instrument that can be used in particular process applications (e.g. safety, control or monitoring).

2. The data (e.g. temperature, DC, pressure) qualified in this document should be confirmed with the product manufacturer.
1.3 Reference documents

- Design and Fabrication of Pressure Vessels according to ASME VIII.
- Design and Fabrication of Pressure Vessels according to BSI PD 5500.
- ISO 10418:2003, *Petroleum and natural gas industries – Offshore production installations – Analysis, design, installation and testing of basic surface process safety systems*.
## 1.4 Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPCS</td>
<td>Basic Process Control System</td>
</tr>
<tr>
<td>DBB/SBB</td>
<td>Double Block and Bleed/Single Block and Bleed</td>
</tr>
<tr>
<td>DP</td>
<td>Differential Pressure</td>
</tr>
<tr>
<td>ETFE</td>
<td>Ethylene/Tetrafluoroethylene Copolymer</td>
</tr>
<tr>
<td>FCC</td>
<td>Federal Communications Commission</td>
</tr>
<tr>
<td>FFT</td>
<td>Fast Fourier transform</td>
</tr>
<tr>
<td>FMCW</td>
<td>Frequency Modulated Continuous Wave</td>
</tr>
<tr>
<td>FPSO</td>
<td>Floating, Production, Storage and Offloading</td>
</tr>
<tr>
<td>GWR</td>
<td>Guided Wave Radar</td>
</tr>
<tr>
<td>ID</td>
<td>Internal Diameter</td>
</tr>
<tr>
<td>LG</td>
<td>Level Gauge</td>
</tr>
<tr>
<td>LNG</td>
<td>Liquefied Natural Gas</td>
</tr>
<tr>
<td>LOP</td>
<td>Layer Of Protection</td>
</tr>
<tr>
<td>LT</td>
<td>Level Transmitter</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
</tr>
<tr>
<td>PPE</td>
<td>Personal Protection Equipment</td>
</tr>
<tr>
<td>PFA</td>
<td>Perfluoroalkoxy</td>
</tr>
<tr>
<td>PTFE</td>
<td>Polytetrafluoroethylene</td>
</tr>
<tr>
<td>PVDF</td>
<td>Polyvinylidene Difluoride</td>
</tr>
<tr>
<td>MLI</td>
<td>Magnetic Level Indicator</td>
</tr>
<tr>
<td>SIS</td>
<td>Safety Instrumented System</td>
</tr>
<tr>
<td>SS</td>
<td>Stainless Steel</td>
</tr>
</tbody>
</table>
2. General

2.1 Pressure vessel connection

Level instrument tapping on vessel outlet piping are not recommended. API RP 551 (reaffirmed in 2007, section 3.2.4) provides guidance with respect to a dynamic flow connection.

Level measurement instruments should be isolatable for maintenance, dismantling/removal and calibration without affecting production, except when stopping the production for such activities is deemed acceptable.

Level instruments may be internally or externally mounted. They should be provided with individual isolation facilities allowing for sensor removal, and cage/chamber cleaning (see Figure 1).

As far as possible, the measurement in the sensor cage/chamber should be representative of the actual level in the vessel. To display a representative level, this might require additional tapping/connection on the vessel.

Isolation valves ID (e.g. used for DP or Radar) should be the same as the nozzle ID.

Level instrument flange should be designed in accordance with the piping/vessel code and material. Flange facing should be free of any coating/insulation and suitable for receiving the piping/vessel gaskets.

Note: Irrespective of the location of instrument nozzles, the weld edge distances requirement from ‘Piping’ Code such as ASME VIII and/or PD 5500 Vessels should have adequate access/distance for constructability and inspection.

![Figure 1 Pressure vessel mounting principle](image-url)
2.2 Vessel bottom connection

Connections to bottom vessel heads should be avoided since exact positioning is difficult, dead legs are created and often the vessel skirt has to be penetrated.

2.3 Range selection

The normal operating/alarm/trip settings should be defined by a combination of process/vessel/instrument operational limits.

Measurement ranges used for process control system (LT for BPCS and LG) and safety instrumented systems (LT for SIS) should generally have the same range and process tapping elevations to allow for continuous monitoring of any discrepancy between various measurements. However, if for accuracy or sensitivity reasons this cannot be achieved, then the process control system measurement range should cover the safety instrumented systems measurement range.

The definition of alarm and trip levels should be reviewed between the process, piping and instrumentation specialists to ensure feasibility. Appropriate (minimum) differential between the alarm and the trip should be considered.

The measuring range should be sketched/defined as in Figure 2:
2.4 Material

All materials used for the level measurement should be selected according to the equipment (e.g. piping, vessel, tank...) and the process fluids.

Unless otherwise specified, wet parts of instrumentation devices (displacer, float, diaphragm..) should be minimum AISI 316 or 316 L SS.

Special care should be taken for selection of material (e.g. gold plated membrane) in contact with low molecular mass fluid or if hydrogen permeation is expected.

Material of housing should be AISI 316 or 316 L SS for offshore. Alternatively, other materials such as A365 grade aluminum (epoxy painted) or GRP may also be used.

2.5 Environment

All devices used for level measurement should be suitable for their environmental conditions. This applies to the temperature, humidity, electromagnetic compatibility, ingress protection as well as the hazardous area. The relevant certification should be provided.

Weight and available space constraints particularly to allow removal of the instrument should be taken into account when selecting a level measurement technology.

Level Instruments should be assessed for the extremes of weather protection including sunshades and protection boxes as required.

2.6 Standpipes vs. sensor cages

The terms standpipe and sensor cages are often mixed up. In order to clarify, the following definitions are used:

- **Standpipe/Bridle**
  This is an external extension of the pressure vessel, to which multiple instruments can be connected. A standpipe should follow the pressure vessel code. Usually no instrument is installed inside the standpipe itself. Isolation valves may be used between vessel and standpipe (as per API RP 551 reaffirmed 2007, Figure 12). Each instrument connected should have its own isolation valves, vents and drain to facilitate maintenance. The distance between the standpipe and the vessel nozzle should not exceed 1 – 1.5 m. Long connections could potentially cause temperature gradients, formation of hydrate and reduction in level coupling between the standpipe and the vessel (refer to API RP 551 reaffirmed 2007, Figure 12).

- **Sensor cage/chamber**
  This is an individual cage/chamber in which the level sensor is installed, part of a single level instrument. The sensor cage/chamber can be attached either directly to the pressure vessel or to a standpipe. The sensor cage/chamber should have dedicated process isolation, vent and drain valves provided. Drain valves should be installed at the bottom connection of the sensor cage and provisions should be made for the appropriate disposal of the drained material. Vent valves are
provided to allow depressurization of the instrument prior to draining. In toxic services, drains and vents should be piped away from the instrument to a safe area or disposal system.

Care should be taken to reduce the temperature gradient between the vessel and the Standpipe/bridle/sensor cage/chamber.

Standpipes, bridle, sensor cages and chambers can be reviewed and assessed for thermal insulation and trace heating requirements.

### 2.7 Level sketches

Level sketches should be prepared at an early stage of the engineering. Level sketches should include details related to nozzle sizes and heights, vessel internal and external supports, material, sensor/source location, etc. in line with the Product Manufacturer recommendation.

Level sketches should indicate all level related instruments (transmitters, gauges, switches) for all applications (i.e. BPCS and/or SIS) with tapping connections and normal operating/alarm/trip settings.

Level sketches should describe level threshold in both ‘length’ and ‘%’ measured range.

Note: Sufficient clearance to facilitate level instrument and chamber/cage draining to a safe location/closed drain system should be incorporated into the design.

### 2.8 Data

Process data should be carefully addressed with all detailed fluid features as well as the different layers to be measured.

From the design perspectives the BPCS level measurement uncertainty should be better than +/- 5% of the reading and the SIS level measurement uncertainty should be better than +/- 2% of the reading.

For floating facilities (e.g. FPSO), the design should take into account the vessel motion (e.g. pitch, roll) which can influence the measurement range and technology selection. Level sketches should integrate the margins of range and thresholds due to the vessel motion.

Local radiation safety requirements, local radio frequency requirements and operational requirements (radiography) and how such events are managed together with environmental data should be taken into account.

#### 2.8.1 Process data

For each level instrument the minimum following process data range (e.g. min, max, operating, and design) should be defined:

- process data (e.g. density/SG, temperature, pressure, dielectric, viscosity...)
- specific service (e.g. corrosive, cryogenic...)
- level measurement requirements (e.g. safety or control application, alarms and trip values...)

12
• presence of other nucleonic isotopes in the fluid
• presence of salt
• presence of oil-film/build-up
• presence of sand/water/emulsion/oil/foam
• the type and name of the substance/process fluid to be measured...

2.8.2 Level data

For each level measurement, the following data should be defined as a minimum:

• available nozzle diameter and flange connection
• vessel internal and external arrangements and layouts
• vessel material composition and wall thickness
• hook-up, location in the vessel and installation
• nucleonic source and detectors calculation note(s)
• nucleonic source intensity
• geometry, distance and location of nucleonic sources and detectors
• operation and maintenance manuals as well as particular instructions (e.g. adjustment and calibration interventions)
• calibration procedure (in factory and in operation)
• additional screening around final nucleonic source container installation location
• dip pipe features (material, thickness, flange diameter...)
• procedures for handling and storage
• certificates of licensing and regulatory requirements...

2.9 Emulsion

An emulsion is a mixture of two or more liquids that are normally immiscible. Emulsions are part of a more general class of two-phase systems of matter called colloids. Although the terms colloid and emulsion are sometimes used interchangeably, emulsion should be used when both the dispersed and the continuous phase are liquids. As an example, oil and water can form, first, an oil-in-water emulsion, wherein the oil is the dispersed phase, and water is the dispersion medium. Second, they can form a water-in-oil emulsion, wherein water is the dispersed phase and oil is the external phase. Multiple emulsions are also possible, including a ‘water-in-oil-in-water’ emulsion and an ‘oil-in-water-in-oil’ emulsion.

Particular attention should be paid to any interface measurement in the presence of emulsion. Density of water in oil emulsion will change depending on water fraction. At high water content (approximately 80% of water-in-oil) the density is comparable to the water. Then density decreases, not necessary linearly, with the decreasing of the volume fraction of water. At a low water content (approximately 20% of water-in-oil), the density drops sharply to the oil value. This means that the emulsion density is not constant. However, the emulsion density can be seen as the average of the oil and the water density. Dielectric or conductivity values of the emulsion follow the same principle of non-linear dispersion. This implies that the emulsion cannot be ‘seen’ easily as a single two fluids interface.

Note: The foam also is a non-uniform fluid; density, dielectric and conductivity parameters vary in a stochastic manner.
2.9.1 Sensor cage/stand pipe interface level measurement with emulsion

An emulsion layer at the interface of two fluids may or may not be seen by the instrument depending upon the hook-up arrangement. When using a sensor cage/stand pipe, the following can be considered:

- Figure 3: the interface level device in the sensor cage/stand pipe does not ‘see’ the emulsion in the vessel, so the measured value only represents the average interface level
- Figure 4: the interface level device in the sensor cage/standpipe ‘sees’ the emulsion layer so the measured value represents accurately the interface level

![Figure 3 Interface level with no emulsion representativeness](image)

![Figure 4 Interface level with emulsion representativeness](image)

Note: the accuracy of the interface level measurement in the presence of the emulsion will depend upon the number of nozzles provided, the selected level sensor technology, the correct specification of the technical data, i.e. SG and thorough commissioning and calibration of the instrument. The number of nozzles that can be provided on a tank or vessel is often limited due to the space and the mechanical integrity of the vessel or tanks. Thus, if accurate level measurement is required in the presence of emulsion, a direct top mounted technology level should be considered.

2.10 Calibration

Calibration should be performed prior to the factory acceptance test and prior to shipment. A calibration certificate should be provided that detail the traceability of the test equipment used. Site calibration should be performed to ensure the factory calibration has not deteriorated during transportation and any site specific requirements are accommodated. Any shipping stops, seals, plastic fitments, temporary grommet seals or guides to ensure safe shipping should be removed prior to fitting and mechanical completion.

Particular attention should be paid to calibration of Radar, GWR, Capacitance and Nucleonic instruments. The lower range value should be calibrated without any process fluids, but as far as possible with all vessel utilities (e.g. energy for electro dehydrators) present. This should take into account any signal noise/disturbance. The higher range value should be calibrated with the maximum fluid level to be measured. Special tools should be provided. Any special sensor or probe coating should not influence the calibration.

Arrangement for in-line calibration and flushing of the instrument is recommended.

Onsite verification should be completed for instruments assigned as part of a LOP, e.g. SIS and critical alarms.
2.11 Stilling wells

A stilling well is a perforated pipe to allow free movement of fluid. This pipe is equipped with a top mounted flange which is supported at the bottom of the vessel. For a long still well, support should be provided along its length; however these supports should not affect the measurement.

Stilling wells provide a stable gauge reference point (limit vertical movement), and provide a relatively ‘quiet’ product surface during filling and emptying of the vessel, especially if ‘swirl’ exists.

Stilling wells may act as a ‘wave guide’ for the radar energy. The well helps to concentrate the emitted signal and minimize the signal loss. The loss of signal is generally due to a low product reflectivity (caused by a low dielectric constant) or surface phenomena like ‘boiling off’ and ‘vapour mist’.

Stilling wells should not be used with viscous fluid, dirty fluid or fluid-film-buildup. Stilling well should be one piece from the top to the bottom (i.e. no gaps).

The following features should be considered for stilling well:

- AISI 316 SS minimum with smooth roughness ≤6.3 µm (no welding parts)
- one piece from the nozzle flange with constant diameter.

Stilling wells slot width/holes diameter should generally be 1/10 of the stilling well diameter with a minimum of 0.635 cm. Spacing between slots/holes should minimum be 15 cm.

Slots/holes should be deburred and their quantity minimized. Holes shape may be slotted or circular. Holes should be on both sides of the stilling well, in order to minimize the risk of plugging especially for waxing service.

Stilling well diameter should be minimum 20 cm (as per API MPMS § 3.1A).

Stilling well design and construction should be approved by the Product Manufacturer.

2.12 Centring disk

Centring disk used in stilling wells should be compatible with the fluid properties (build-up, viscosity...) and mounted outside the measuring range. Consideration should be taken into account when using a weighted bottom mounted on the rod instead of using centring disks. Centring disks should be provided as per the Product Manufacturer recommendation.

2.13 Control and safety

Level measurements should be designed to ensure that the likelihood of common cause, common mode and dependent failures between monitoring, control or safety protection layers are addressed.

This design should consider the following:

- independency between protection layers
• diversity between protection layers
• physical separation between different protection layers
• common cause failures between protection layers.

As such, differing measurement principles are recommended for control and safety functions.

With reference to ISO 10418 issue 2003, § 6.2.9.

“The two levels of protection shall be independent of, and in addition to, the control devices used in normal process operation” it is suggested to change the recommendation to a requirement for separate nozzles.”

The safety function should provide a reliable and sufficiently fast detection of process upsets. Since the control function can both work as back-up as well as comparison of the safety function equal performance is recommended for control (accuracy and trip point should be considered).

If shutdown measurements require input from other variables (e.g. temperature and pressure) to calculate the correct value, these inputs should be separate for control and shutdown functions.

It should not be possible to inadvertently isolate instrumentation for shutdown functions from the process.

Level instrumentation used on process vessels, should be designed so that one of the level instruments used for control and safety, should not be affected by radioactive disturbance from tracers, scale and x-rays.

Level gauge is recommended for the entire measuring range. Level gauges are used for local operation and as reference to level instrumentation.

If multiple level devices are required (e.g. one device for control and second device for alarm, or potentially several devices as part of a SIS), the use of diverse level technologies should be assessed.

Consideration should be given to comparison of different devices used on the same duty, with cross comparison and alarms function from a deviated percentage, i.e. 5%.

2.14 Heat tracing

All instrument nozzles should be located such that the risk of blockage and solidification in the nozzle is minimized. If there is risk of hydrate formation or freezing in the instrument nozzles or instrument impulse lines, application of heat tracing should be considered. Note, however, that there may be safety requirements connected with the heat tracing, i.e. hazardous area equipment requirements or over temperature protection.

2.15 Maintenance access

All level instruments should be designed for long term stability and operation. Intervals for planned production stops are normally two years or longer.

Relief/drainage tubing or pipe should be routed to a safe location according to area requirements, i.e. to a safe location/closed drain system.

Maintenance operation should take into account the hazardous area certification type e.g. Ex ia/ib, Ex d...
Level instruments do not normally require readability from deck. Level gauges or indicators should be readable from deck or permanent platform.

Isolation valves should be available for operation.

### 2.16 Service capabilities

During the design phase it is recommended to include the Product Manufacturer in the proper design, construction and installation of the facilities (e.g. level sketch, hook-up, stilling wells).

At site, the Product Manufacturer should have the capability of assisting in the commissioning and start-up activities, providing specific training, performing site calibration and issuing specific detailed maintenance procedure for equipment cleaning and replacement.

The Product Manufacturer should provide a comprehensive spares listing, part numbers and the time taken to expedite basic consumable items.

The Product Manufacturer should provide obsolescence plan to indicate spare part availability for each model for users to plan for upgrading or stocking plan as appropriate. Life cycle cost (i.e. total cost of ownership) may be evaluated for selection of measurement technology.

These spares should be added to the maintenance management systems that logs and details the installed device on the specific site and installation.
3. Differential pressure transmitter

3.1 Measurement principle

The principle of differential pressure level measurement is based on hydrostatic head.

Hydrostatic pressure measurement is the most common means for liquid and interface level measurements. For most applications, differential transmitters are preferred because the range selection is flexible and widely understood. They are used with open and enclosed vessels. Differential transmitters are usually connected to the side of a vessel or tank with isolation facilities.

3.1.1 Interface liquid–liquid level calculation example

The differential pressure $DP = h_{\text{interface}} \times g \times [\rho_2 - \rho_1] + \rho_1 \times g \times H$ (Equation [1]).

The range is:

- At $h_{\text{interface}} = 0$ -> $DP = \rho_1 \times g \times H$
- At $h_{\text{interface}} = H$ -> $DP = \rho_2 \times g \times H$

![Figure 5 DP measurement](image.png)

$\rho_1$: Liquid1 Density (kg/m³)

$\rho_2$: Liquid2 Density (kg/m³)

$h_{\text{interface}}$: Interface Level between the Liquid 1 and Liquid (m)

$g$: 9.81 (m/s²)

Interface measurement requires its own connection into the upper and the lower phase.

Equation [1] is applicable if there is only one variable. For an interface level measurement it should be $h_{\text{interface}}$.

Using the same principle and Equation [1], density of a single fluid can be measure if both tapping are permanently and fully immersed.
Following the principle, measurement of several interface layers can be considered by staging each interface level measurement. For an interface measurement between two liquids the limitation is derived from Equation [1].

The combination of density difference and the distance between the upper/lower nozzles should result in a minimum DP range of around 30 mbar.

### 3.2 Limitations

If both density values \( \rho_2 \) and \( \rho_1 \) are similar, the interface level measurement may nearly not be detected by the transmitter. This depends on the DP range, accuracy and distance between the upper and lower nozzles. This occurs typically for an interface measurement between oil and water the case of presence of ‘heavy’ oil (the oil density value is nearly the same as the water density value).

Accuracy depends on the liquid density variation. To compensate a density measurement should be provided.

For vessel under vacuum, DP with remote diaphragm seal is recommended. The transmitter should be installed below the bottom nozzle.

For heavy crude oil dirty, foaming, fouling or clogging services the DP with remote diaphragm seal is recommended with nozzle, flushing ring and heat tracing (e.g. freezing oil) as required.

The mounting of heavy instrument (including all accessories, i.e. DBB/SBB valves, flushing ring, etc.) to the nozzles should be verified with the nozzle local stress verification (static and dynamic/fatigue). Sufficient support should be provided for minimizing the weight transferred to the nozzles.

### 3.3 Selection

Differential pressure measurement could be considered for most applications with liquid–gas or liquid–liquid interface level measurement.

Differential pressure transmitters can be used in severely turbulent, dirty, in presence of foam above the liquid or fouling service with diaphragm seals and capillaries.

Differential pressure transmitter with diaphragm seals and capillaries are preferred. This should be provided with a flushing ring mounted between the process flange and the diaphragm seal.

Capillaries should be specified at the correct length, without the need for coiling excess capillary that is surplus to the run. Capillaries should be protected from damage using a basic channel system, allowing sufficient bend radius for the capillaries.

Diaphragm material should be carefully selected according to the type of fluid (e.g. gold plated in presence of hydrogen).

The use of wet legs with intermediate liquids and zero adjustment implies more complex range calculation and higher maintenance needs. Differential pressure transmitter used without diaphragm seals and capillaries should have block and bleed valve manifolds as a minimum. In vapour or cryogenic services, the dry leg should have a self-purge.
A particular attention should be paid to the protection and heat tracing of dry/wet legs. For capillary tubing, the selection of tubing fluid should consider the ambient temperature (to prevent freezing).

The mounting of heavy instrument (including all accessories, i.e. isolation/drain valves, flushing ring, etc.) on the nozzles should be verified with the nozzle local stress verification (static and dynamic/fatigue). Sufficient support should be provided for minimizing the weight transferred to the nozzles.

High static pressure can create a measurement zero and full scale drift. This can be compensated as required, by measuring and compensating the static pressure.

For low range (e.g. below 300 mm) or similar densities between two liquids (for an interface measurement), a particular attention should be paid to sources of measurement error, such as:

- temperature/density variation of capillary fluid
- measurement resolution error due to 2” or 3” nozzle and diaphragm
- zero error due to air/liquid pockets in the hook up/transmitter or fouling of the diaphragm
- uncertainties of the transmitter when maximum possible calibration range of the cell is much greater than actual calibrated range.

### 3.3.1 Impulse piping

For atmospheric vented vessel the low pressure side is connected to the atmosphere. Wind effect or insect should not affect the measurement (e.g. using a bug filter).

The impulse line is used to interface the instrument with the process connection. There are two methods which could be used to connect the instrument the process:

- using a wet leg
- using a dry leg.

![Bug filter](image)

**Figure 6 DP Impulse**

**Wet leg**

If the ‘reference leg’ is filled with a liquid, a permanent zero offset will be created. This offset should be compensated.

The wetted leg liquid should be selected for avoiding the risk of evaporation and leakage.

A trifoliate label in the field should be affixed to the three-way manifold block, highlighting “This level duty is on a wet leg system. Equalization of the transmitter block will result in loss of the wet leg.”
Dry leg
Gas compatibility with the dry leg material should be considered. Gas change state or liquid presence in the dry leg should be carefully addressed.

Where use of Differential Pressure dry leg system are deployed on a closed tank, they should be assessed to ensure no excess fluid or condensate can build up in the low pressure (dry) impulse leg.

Dry legs should include an isolable drainage pot at their lowest point (below HP tap) for allowing the condensates to be drained.

3.3.2 Remote diaphragm seal
Diaphragm seal capillaries filled with oil requires a dedicated configuration of the range with a zero drift.

In case of tall measurement range (e.g. above 6 m), two separate remote sensors may be used. The measurement principle is based on a remote sensor replacing the capillaries. In this case, a detailed procedure for the calibration (including the zero shift) should be studied.

For density measurement the liquid should always above the upper nozzle.

![Figure 7 DP Level vs density measurement](image)

3.3.3 Symmetric and asymmetric capillaries
Differential pressure seal system is typically specified with identical capillary lengths and seal configurations on both the high and low pressure process connections. This type of system is traditionally specified because it compensates for temperature induced errors.

The oil volume in the capillary will expand and contract causing fluctuations in the internal pressure of the capillary system. This error will be cancelled out because the same expansion and contraction of oil volume will occur on both the high and low sides of the transmitter due to symmetrical construction. The second source of temperature induced measurement drift occurs when a capillary seal system is installed with a vertical separation between the two seals. The density of the fill-fluid within the capillary will fluctuate with the change in temperature and cause the amount of head pressure force that is measured by the transmitter to vary.
Equal lengths of capillary cannot compensate this change in density due to low pressure side generally being mounted at a higher elevation than the high pressure side. An asymmetrical design minimizes the fill-fluid volume on the high side in order to counteract the temperature induced density effects always present on any vertical installation (see Annex D).

3.3.4 **Electronic DP level system**

This measurement principle is based on independent pressure measurements. Rather than using a single DP transmitter with mechanical impulse piping or capillary, electronic DP level system uses two direct mounting gage or absolute sensors that are connected with a non-proprietary electrical wire.

Electronic DP level system replaces the long lengths of oil-filled capillary and impulse piping with an electrical wire that is immune to temperature induced effect as well as the lengthy capillary. This means that it will be possible to get an accurate measurement over a large range of ambient temperatures without fill-fluid density or volume changes affecting the reading. High and low pressure measurements are fully synchronized to ensure that the differential pressure measurement is accurate.

If the ratio between the DP pressure and the vessel static pressure is \((\text{DP}/\text{Static}) < 1/10\) the impact on the accuracy will be non-negligible.

The effect of a static pressure on both side of a non-electronic DP system implies a drift that needs to be compensated. Electronic DP system calculates and compensates the pressure effect directly without specific calibration.

Electronic DP Level system solves many of the problems that are traditionally seen when making a DP measurement on tall vessels or towers. Typical problems are:

- Mechanical installation constraints: two remote seals + capillaries
- Ambient Temperature effect on the capillaries (fill fluid dilatation/contraction and density variation) results of inaccuracy: insulation or heating tracing of capillaries
- Plugging condensation/evaporation of reference column
- Tall measurement range (e.g. above 6 metre).

Note: One of the two sensors calculates the DP and transmits it back to the host system.

3.4 **Design**

3.4.1 **Level measurement**

DP Transmitter signal variation should be directly proportional to the level variation. HP and LP chamber location (i.e. vessel vs dry/wet legs side) should be studied accordingly. Differential pressure transmitters installed above or below the liquid level range or with dry/wet legs may require a zero shift.

For slurry and/or sludge application extended diaphragm may be used. This would eliminate the dead-ended cavity typically present in the nozzles installed with standard diaphragm seal and minimize error to measurement. The drawback of this is no isolation valves could be installed due to the extended diaphragm

22
inside the nozzle. Total shutdown and isolation of the tank or vessel may be required to remove the diaphragm for maintenance.

3.4.2 Range

Ranges for differential pressure transmitters should be calculated using the minimum following information:

- exact distance between the vessel nozzles
- specific gravity of liquid in vessel according to the temperature and pressure ranges
- specific gravity of upper and lower fluid for transmitters in interface service
- specific gravity of liquid in the reference leg (if applicable)
- Instrument elevation in relation to higher and lower tapping points
- at high operating pressures, zero compensation for gas phase weight/density.

For example see PIP PCEL001 revision 2014, Appendix B.

3.4.3 Process connection with no diaphragm

Differential pressure transmitters with no remote capillaries seals should have their location as follows:

- keep the impulse tubing as short as possible
- for liquid tapping connection, slope the impulse tubing at least 1 in./foot (8 cm/m) upwards from the differential pressure transmitter towards the vessel connection
- for gas tapping connection, slope the impulse tubing at least 1 in./foot (8 cm/m) downwards from the differential pressure transmitter towards the process connection
- avoid high points in liquid lines and low points in gas lines
- make sure both impulse legs are the same temperature
- use impulse tubing large enough to avoid friction effects and clogging
- prevent sediment deposits in the impulse tubing
- select instrument manifolds with front facing process connections to avoid pockets in the hook up.

On duties that are fouling, a purge to keep the system clear should be used. The purges work with a constant pressure delivered using a rotameter or pneumotstat system, typically with an inert gas.
3.4.4 Process connection with diaphragm

Differential pressure transmitters with diaphragm seals and capillaries should be considered taking into account the following consideration.

When flange reducer is necessary, due to a smaller process connection (25 mm or 50 mm) compared to the 75 mm diaphragm, it is recommended to use flushing and draining connections.

In case there is a risk of freezing liquid in the chamber of the flange adapter/reducer or a high viscosity heat tracing or heating circuit should be considered. Heating medium (steam/oil) should not exceed the fluid boiling point.

Process temperature and ambient temperature should be considered to avoid the fluid boiling or affecting the measurement reaction time (in case of higher fluid viscosity). In a vacuum application this may cause the fluid to reach the boiling point and consequently to blow up the diaphragm and destroy it.
Diaphragm material should be carefully selected according to the fluid properties (e.g. gold plated in presence of hydrogen or subject to hydrogen permeation).

Flange connection should be selected according to the piping/vessel code.

The inner volume of capillary fluid can affect the measurement accuracy and response time. Capillary with internal 1 mm diameter will minimize the effect of temperature variation but will increase the response time. Capillary with internal 2 mm diameter will decrease the response time but will more affected by the fluid dilatation.

Seal fluids compatibility with the line process fluids should be reviewed to confirm it is suitable and prevent contamination of the process stream (e.g. oxygen service).

In the presence of wax, slurries, clogs flushing rings should be considered. Flushing rings should be fitted with vent and drain facilities. Diaphragm seals should include isolation features to enable maintenance.
3.5 Installation

Capillary filled seal is sensitive to ambient temperature variation. Protection such as insulation shield, protective cover or installation facing the North should be considered.

Diaphragm seals should have facility to maintain, remove, vent and drain (e.g. isolation features).

The flange fitting should be installed in a vertical orientation. Diaphragm and capillary should be installed in a vertical position.

![Figure 12 DP capillary protection](image1)

The differential pressure transmitter should be mounted below the lowest level to be measured.

The capillary position should avoid any risks of vaporization.

![Figure 13 DP Capillary arrangement](image2)

Capillaries should have a minimum radius of curvature of 150 mm, any vibration or friction should be avoided.

Diaphragm seals should be properly handled in the field to avoid damage to diaphragm seal and capillary tubing and potential loss of sensing fill fluid.
3.6 Calibration and configuration

Calibration should be performed at Product Manufacturer premises and verified prior to the commissioning activities. Calibration certificate should be provided.

Calibration may be performed in situ using a field pressure calibrator or using a calibrator bench (e.g. for diaphragm seal or specific low pressure).

3.6.1 Getting started, zero adjustment, scale with seals

The oil column height should be taken into account to a zero offset:

- When the tank is empty, the sensor measure the LP weight of the oil column, this value causes a zero offset in the negative, which can be adjusted at the span calibration or during the commissioning by a zeroing with empty vessel.
- Delta scale (or span) by calculation, will normally be adjusted relative to the distance between flanges and to the density of the liquid, then add to the calculated zero value. Or it can be done with full vessel.
- Zero offset can be therefore even more important than the scale itself (especially with the fluorinated oil). We should choose a sensor whose extent of adjustment allows the zero offset.
- For density or multi-layer measurements, it will be necessary to make the zero by adjustment with 100% of the lightest liquid, full scale will be calculated with 100% of the heaviest liquid.

3.6.2 Getting started, zero adjustment, scale with impulse line dry leg on low pressure side (LP)

LP side (upper connection), column vented to vessel atmosphere:

- When the tank is empty, the sensor measure zero on both side (HP and LP), then DP (differential pressure) is also zero = 4 mA.
- When the tank is full, measurement is height multiply by density, calibration is done for 100%, In case it is possible to know an intermediate level, calibration could be done for another percentage.
- Most important thing: “This required that liquid should not arrive into the upper connection, or the dry leg will be filled and this will make a offset of the zero”.
- For density or multi-layer measurements, height should be constant, then using a dry leg is clearly not possible, measurement should be done in a vessel which works with an overflow.
4. Displacer (buoyancy)

4.1 Measurement principle

The principle of displacement level measurement is based on Archimedes Principle. Displacement instruments determine liquid level by sensing the buoyant force exerted on a displacer by the liquid it displaces. Unlike floats, in float-type level instruments, the displacer moves very little relative to the rising or falling liquid.

4.1.1 Interface liquid–liquid level calculation example

The apparent Force \( Fa \) = Buoyancy weight \( F \) – Archimedes force \( Pa \) – See Figure 14.

The apparent mass is \( \frac{Fa}{g} = Ma = m - \rho_1 \times S \times H - S \times h_{interface} \times [ \rho_2 - \rho_1 ] \) \hspace{1cm} (Equation [2])

The range is:

- At \( h_{interface} = 0 \) -> \( Ma = m - \rho_1 \times S \times H \)
- At \( h_{interface} = H \) -> \( Ma = m - \rho_2 \times S \times H \)

\( h_{interface} \): Interface Level between the Liquid 1 and Liquid 2 (m)

\( \rho_1 \): Liquid1 Density (kg/m³)

\( \rho_2 \): Liquid2 Density (kg/m³)

\( g \): 9.81 (m/s²)

\( S \): Displacer section (m²)

\( H \): Displacer length (m)
Interface measurement requires its own connection into the upper and the lower phase. Equation [2] is applicable if there is only one variable. For an interface level measurement, there should be an interface. Equation [2] can be used to measure the density of one fluid. In this case, the displacer is fully immersed in the fluid.

4.2 Limitations

The level reading from the displacer can be incorrect if the temperature and/or density of the liquid in the vessel is different from that of the liquid in the external cage.

Unreliable measurements are due to dirty, foaming, fouling service as well as turbulent fluid or presence of solid particles in the fluid (e.g. sand).

Vibration (e.g. false alarm) and corrosion affect the level measurement.

Displacers can measure only the range of the displacer length. If the level rises above the top of the displacer, the displacer cannot measure the level.

Displacement transmitters can have higher maintenance needs. Many faults are due to encrustation, freezing of the torque tube, displacer hanger broken or detached, failure of electronic detector angular motion, displacer stuck, and displacer mass change due to corrosion...

Additional features may be required to eliminate turbulent liquid effects on the displacer.

Displacement transmitters can be much more difficult to calibrate, particularly if used for interface measurement.

Removal of the displacer from a vessel may require special rigging.

Displacers are available in a few standard lengths, e.g. 0.36 m to 0.81 m lengths being most common.

4.3 Selection

Displacement transmitters can be used in a wide range of temperatures and pressures.

Displacement transmitters should be suitable for interface level measurement if specific gravities differ significantly and the change in specific gravity due to composition or temperature cannot affect the reading. It is admitted that the difference between specific gravities is greater than 0.1 (if the gravity difference of 0.1 is used, the impact on the accuracy needs to be assessed).

Displacement type level instruments should not be used in severely turbulent, dirty, foaming, fouling service or in case of presence of solid particles in the fluid (e.g. sand). These conditions lead to unreliable measurements from displacement level instruments.

Displacement type level instruments should not be used for liquid-liquid interfaces where there is potential emulsion forming.
Displacement type level instruments should not be used in liquid-liquid or liquid–gaseous services where either the upper or lower fluid specific gravity is not relatively constant.

Displacement transmitters can be use also for density measurement if the displacer is permanently and fully immersed in a single fluid.

4.4 Design

Displacers should be made of stainless steel or other material compatible with the process fluid.

Displacer should have the height according to the level range for the application.

4.5 Installation

The preferred installation for displacers should be a cage/chamber and installed externally to the vessel. Block, drain and vent valves should be installed to fill and empty the chamber to carry out maintenance activities.

Vessel nozzles should be located with respect to measuring interface level.

Instrument connections directly at the bottom of the vessel should be avoided.

4.6 Calibration and configuration

Calibration should be performed at Product Manufacturer premises and verified prior to the commissioning activities.

Calibration may be performed in situ or on a bench calibration with weights. Bench calibration with weights should be performed using the apparent mass.

In situ calibration should be performed using a level gauge or sight glass if fitted. Otherwise, a clear flexible external tube could be used.

Figure 15 describes a typical arrangement which should be used to calibrate chamber mounted instruments in situ.
Figure 15 Displacement in situ calibration
5. Ultrasonic

5.1 Measurement principle

Continuous non-contacting ultrasonic level measurement is based on the time of flight principle.

An ultrasonic level instrument measures the time between sound energy transmitter from the sensor, to the surface of the measured material and the echo returning to the sensor.

As the speed of sound is known through the travel medium at a measured temperature, the distance to the surface is calculated. Level can be calculated from this distance measurement.

Echo Processing built in to the instrument can allow the instrument to determine the material level of liquids, solids or slurries even in narrow, obstructed or agitated vessels.

5.2 Limitations

Ultrasonic is seldom used in upstream hydrocarbon process stream for level measurement; it might be used in atmospheric utilities applications. In applications which are susceptible to vapour density variation, compensation reference pin should be used.

Maximum measurement distance should be checked against the technology (above 30 m the reflectivity may be reduced and might cause a measurement error/problem).

Ultrasonic sensors have, as physical limitation, a blocking distance (close to the sensor) where they cannot measure reliably, e.g. 0.25 metres.

Vessel pressure limitation should approximately be, e.g. 0.5 bar or less. Higher pressure may introduce uncertainty in the level measurement.

Vapour, vacuum or temperature gradients can influence the speed of sound and consequently can cause incorrect measurements.

Presence of foam or heavy turbulence on the surface of the measured material can cause unreliable measurement.

5.3 Selection

As ultrasonic is non-contacting, even abrasive or aggressive materials can be measured.

Vessel height and head room should be considered to select an instrument with suitable minimum and maximum range.

5.4 Design

Ultrasonic sensors should be made of a material suitable for the measured medium (e.g. PVDF or ETFE).

Solid construction and a self-cleaning action on the face of the sensor provide a reliable, low maintenance product.
5.5 Installation

Sensors may be mounted at the top of the vessel (or container) or in a sensor cage.
Any filling streams should not intersect the beam path of the sensor.
An unobstructed view of the material from the sensor is best. Echo processing can work around all but the most invasive obstructions.
Sensor position in the middle of the tank may cause multiple reflections; this is not a preferred location.

![Figure 16 Ultrasonic Liquid Measurement Arrangement](image)

Use of a submergence shield on a sensor will allow an ultrasonic instrument to operate in potential flooding conditions reporting a full vessel to a control system or continuing to operate pumps to remove the flood condition.
Performing an initial or ‘empty calibration’: In this principle, ‘enter’ the distance E from the sensor face to the minimum level (zero point). It is important to note that in vessels with parabolic roofs or bottoms, the zero point should not be more distant than the point at which the ultrasonic wave reflects from the tank bottom.

When possible, a flat target plate that is parallel to the sensor face and directly below the sensor mounting position should be added to the bottom of the vessel for best empty tank performance.

Once the empty distance has been set, the high calibration point or 100% full point can be set. This is done either by setting the distance from the sensor face to the 100% full level or by entering a span (level) from the 0% or low calibration point to the 100% full level.

During commissioning, ensure that the 100% full or high calibration point does not enter the ‘blocking distance’ or ‘blind zone’ of the respective sensor. This will vary from sensor to sensor. Blocking distances or blind zones can be extended to avoid false high level reflections caused by obstructions, but they can only be reduced to a certain distance due to the physical limitations of the sensor itself. The minimum level (distance E/zero point) should be configured. This zero point should be above any dished boiler heads or conical outflow located at the bottom of the tank/vessel.

The maximum level (distance F/full span) should be configured. This distance F should take into account both BD ‘blocking distance’ and SD ‘safety distances’.

Where BD represents a dead zone in which the wave cannot make any measurement and SD corresponds to a warning or an alarm zone.
6. Capacitance

6.1 Measurement principle

The capacitive measuring principle is based on the method of the operation of a capacitor.

A capacitor is formed by two differently charged electrodes isolated from each other. Applying an alternating current between the electrodes will create an electric field. This electrical field depends on the distance between the electrodes, the size of electrodes surface, and the isolating medium between the electrodes.

If the distance between electrodes and size of surface of the electrodes are kept constant, only the medium would have an effect on the electrical capacitance. When the medium change the electrical field changes also consequently the capacitance evolves as follows:

- Capacitance \( (C) = \text{Dielectric constant (}\varepsilon_0\text{)} \times \text{Relative Dielectric constant (DC)} \times \text{Electrode Surface Area} \)
  
  Where the dielectric constant \( (\varepsilon_0) \) is the electric field constant \( (\varepsilon_0 = 8.8 \times 10^{-12} \text{ C/(Vm)}) \).

![Figure 18 Capacitance measurement principle](image)
6.1.1 Interface

Media with a low dielectric constant (DC value) cause very small changes of the capacitance value in level measurement while media with a high DC value produce respectively large capacitance changes. In many interface applications, the medium with the lower DC value is on top, e. g. hydrocarbon (DC = 2) on water (DC = 80).

The upper medium provides only a minimum contribution to the overall capacitance value – only the water level (the interface layer) is thus indicated as level.

In order to make use of this effect, the DC value of the two media should be sufficiently different from each other.

Usually a medium with a low DC value is non-conductive while a medium with a high DC value is conductive. Therefore interface measurement with a non-conductive and a conductive medium is always possible.

6.2 Limitations

If a process coats or fouls a capacitance probe, a compensation option may be required to prevent false high-level readings.

Continuous level capacitance transmitters require that the liquid being measured remains at a constant dielectric value. If this is not the case, the transmitter should have the capability to compensate for the liquid dielectric variation.

Probes mounted directly in the vessel typically cannot be replaced with the process in service unless they are mounted in a sensor cage with isolation valves.

The rod probes require sufficient height clearance, depending on the length of the probe.

It cannot measure liquids which have a viscosity above 2000 cst.
6.3 Selection

The capacitive level measurement can be used in aggressive media when a fully coated probe (e.g. PTFE) is used.

Capacitive measurement has a very fast response time which makes it ideal for processes with fast level changes and small containers.

The measurement principle is not affected by the density variation of the media.

For interface measurements a conductive and non-conductive media is required.

At this interface the difference between the conductivity of the conductive media should be greater than 100 $\mu$S/cm and the conductivity of the non-conductive media should be lower than 1 $\mu$S/cm.

An oil-water emulsion has all the conductivity range between 1 and 100 $\mu$S/cm depending on the oil-water bubble repartition. This means that a capacitance probe will detect the media above 100 $\mu$S/cm (i.e. conductive media) and will not detect the emulsion layer (between 1 and 100 $\mu$S/cm) as well as the non-conductive media layer (i.e. <1 $\mu$S/cm).

Non-conductive build-up on the probe affects the measurement.

6.4 Design

The probes should be made of metallic, conductive electrode with full plastic insulation regardless of the conductivity of the medium.

When mounted, a good electrically conductive connection between the process connection and the tank should be ensured. An electrically conductive sealing band can be used.

Rod probes with a ground tube should be used in the event of severe lateral loads.

The length of the probe should be designed in accordance with level measurement range.
6.5 Installation

The vessel earthing (grounding) method, which can be critical to the operation of the device, should be assessed.

6.6 Calibration and configuration

Capacitance probes are calibrated at the factory for media with a conductivity ≥100 µS/cm (e.g. for all water-based liquids, acids, alkalis...).

A site calibration is only necessary if the 0%-value or the 100%-value should be adjusted to suit specific measurement requirements (e.g. tank/capacitance distance <250 mm, conductivity <100 µS/cm or specific range).

A distinction is generally made between two types of calibration:

- Wet calibration: The probe can be calibrated for its full range i.e. lower level (0% level calibration) and high level (100% level). Other intermediate values can also be performed.
- Dry calibration: The level capacitance can be simulated by entering the low and high level values. Capacitance units will calculate automatically the capacitance variation image based in the factory calibration for a conductivity ≥100 µS/cm.
Figure 21 Capacitance calibration
7. Non-contact radar

7.1 Measurement principle

A radar transmitter should be mounted on the top of a tank, chamber/cage or standpipe. The transmitter sends out microwaves via the antenna, which then travel down to the product surface. At the product surface, they are reflected back to the antenna of the radar transmitter. The propagation velocity of microwaves in free space is the speed of light (~300,000 km/s).

Two different principles are used to measure the extremely short transmission times: Frequency Modulated Continuous Wave (FMCW) and pulse technology. The FMCW method emits microwaves continuously over a narrow frequency sweep. The frequency of the return reflection is slightly different from the frequency currently being transmitted, and the frequency difference is proportional to the distance. Because of multiple reflections, there are several signals mixed together. Therefore an FFT calculation has to be done internally by the radar transmitter to determine all the different single frequencies. This information is used to calculate an echo curve, from which the system can calculate the distance.
The method consists of the emission of microwave energy pulse. The time that needs to receive a return reflection is measured. This time is the image of the level (i.e. level = velocity × time). Because of the high propagation speed (300,000 km/s) the radar transmitter can repeat this several million times in a second without having any interference between the individual signals. These signals are periodical. So the sensor sees the same echo curve several million times during one second. A special sampling method makes it possible to expand the time of this fast echo curve into a slower time range.

FMCW and pulse technologies produce the same result: an echo curve. In the past, the lower power consumption of ‘pulse’ technology has been an advantage for building a loop-powered radar transmitter. Nowadays, both technologies deliver the same performance. There are no longer any major differences between these two measuring principles when it comes to accuracy, dynamic range, measuring range or response time.

Radar transmitters are available with different operating frequencies. For the measurement of liquids, there are low frequencies (between 4.5 – 10 GHz) sensors and high frequency (24 – 27 GHz) sensors.
Note: The higher radar frequency is, the narrower the radar beam angle of the sensor is. For example, with a 26 GHz radar and an antenna aperture of 80 mm the beam angle is about 12°. With 79 GHz radar and an antenna aperture of 80 mm the beam angle is only about 4°.

7.1.1 License

Local licensing requirements should be considered. Radar systems emit radio frequency energy; many countries require licensing under the communications regulatory agency when over some defined power level.

7.2 Limitations

Radar installations require consideration of vessel geometry, nozzle location and size. For that reason, the focusing (beam angle) of the antenna has to be taken into account. This is more a concern for transmitters with low frequencies (4.5 – 10 GHz) than for those with higher operating frequencies (24 – 27 GHz).

Internal obstructions such as heating coils, standpipes, agitators, etc. need to be considered. This is more a concern for transmitters with low frequencies (4.5 – 10 GHz) than for those with higher operating frequencies (24 – 27 GHz).

Installation and troubleshooting may require product manufacturer-specific training and a laptop PC with product manufacturer software.

Pure ammonia, vinyl chloride or methyl chloride level cannot be measured with radar range of 24 – 27 GHz. This is due to the relevant gas vapour which damps the 24 to 27 GHz waves. For this application, radar within the 4.5 – 10 GHz can be used.

Heavy, thick foam has a substantial damping effect on microwaves. A particular attention should be paid to the foam formation during the design phase. If the process generates thick foam that results in excessive damping, radar is not recommended. Consequently, it is not possible to recommend any specific frequency for foam application. Sensors with increased sensitivity for foam applications are available.

Radar transmitters can measure a gas–liquid interface but not a liquid–liquid interface.

If the dielectric constant (DC) of the product is lower than 1.4, it has to be taken in account to choose the sensor or the mounting which fits the application. The dielectric DC is the ratio of electric permittivity of the product to the free space permittivity. The higher the dielectric constant, the stronger the signal reflected by the product. The dielectric constant of the product has less influence on the accuracy, because it changes only the amplitude and not the position of the echo on the echo curve, but more influence on the reliability of the measurement. See Figure 27.
With modern high quality radar, it is nowadays possible to measure even the products with the lowest dielectric constant like LNG/LPG in liquids. For older or less sensitive radar transmitters, it might be required to install a stilling well to measure LNG/LPG. Some product manufacturers have models available with a special electronic. This special electronic increases the sensitivity to allow the LNG/LPG measurement without a stilling well. In general, for products lower than DC <1.4, the product manufacturer’s recommendation should be required.

<table>
<thead>
<tr>
<th>Product</th>
<th>Dielectric constant DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>1</td>
</tr>
<tr>
<td>LNG</td>
<td>1.4</td>
</tr>
<tr>
<td>Oil</td>
<td>2 – 4</td>
</tr>
<tr>
<td>Water</td>
<td>80</td>
</tr>
</tbody>
</table>

Table 1 Example of product dielectric constant

Note: Due to the low dielectric constant of some material, it’s possible to measure through plastic, glass or ceramic.
7.3 Selection

Very strong turbulences on the product surfaces are able to reflect the microwaves in different directions. This will decrease the echo amplitude as well. In very strong turbulences, like a reactor with a strong agitator this has to be considered for the mounting position of radar. The radar transmitter should be positioned behind a baffle. This allows a very easy and repeatable measurement.

Whether Radar is used on turbulence surface a stilling well or sensor cage should be considered. Sensor cage or stilling well should minimum have same ID as radar horn diameter.

Vapour condensation and deposits can affect the radar measurement performance. In this case, necessary heat tracing and a round piece of PTFE may be installed in the mounting flange to prevent the accumulating on the radar gauge cone. A use of a purge may also be considered.

The use of a PTFE shield on the radar cone prevents corrosion.

Radar mounted directly on vessel which cannot be shut-downed should be provided with isolation valves (full bore type).

Radar transmitters are available with a wide range of antenna designs and sizes for different applications.
Radar transmitters are available with different materials, seals and housings to fit the process conditions and environment.

Low frequency (4 – 10 GHz) is preferred when measuring in vapour and foam.

High frequency (above 25 GHz) is preferred in most other applications due to greater mounting flexibility. (A small beam angle is easier to install.)

High Frequency Microwaves are suitable for most application, have less installation considerations, have narrow beam angle avoids disturbances more easily and provide longer measuring range due to more focused energy.

Low Frequency Microwaves provide longer wave lengths which penetrate foam, heavy vapour and condensation more easily. Wide beam angle can in some cases pass disturbances more easily (when the disturbing echo is located directly under the radar).
7.4 Design

Different antenna sizes and types are available to fit with the hook up requirements.

<table>
<thead>
<tr>
<th>Horn antenna</th>
<th>Parabolic antenna</th>
<th>Encapsulated horn antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suitable for most application</td>
<td>Long range application (e.g. more than 50 m)</td>
<td>Condensation Aggressive/corrosive fluid</td>
</tr>
</tbody>
</table>

Figure 29 Radar antenna shape

There are different antenna sizes and designs available. Bigger diameter horn antenna is the preferred solution as this provides a more focused beam. However, the antenna also needs more space and therefore the process connection is getting bigger.

The encapsulated horn antenna is especially made for aggressive or corrosive applications. The only material which is in contact with the medium is PTFE or PFA (there are no seals or metal parts in contact with the medium).
7.5 Installation

Radar transmitters can be directly mounted on the top of the vessel, without any valve or standpipe. This installation principle can be used if the process can be shut-downed when the radar needs maintenance.

When radars are installed in a nozzle, actual vessels or tank drawings should be checked before selecting the antenna size (e.g. Nozzle IDs may be smaller than expected. This typically occurs in high rating flange or specific features such as Long Weld Neck flanges).

![Figure 30 Radar Direct top vessel Installation](image)

The sensor should be mounted perpendicular to the surface. The mounting socket on top of a vessel should be as short as possible. In the case of instruments with horn antennas, the length of the socket should be less than the length of the horn antenna.

![Figure 31 Radar alignment](image)
If an access to the antenna is required (e.g. maintenance/operation) a full bore ball valve should be used. Note: Electronic of non-contact measurement are generally removable without a process shutdown.

This reduces the influence on the microwave and allows a reliable and accurate measurement. Full bore valve is a solution if there is need to remove the cone antenna for maintenance (cleaning). Radar electronic can be changed without opening the tank.

When installing a non-contacting radar sensor on a stilling well or chamber/cage tube, the ID should minimum be the horn diameter.

Note: If the stilling well or chamber/cage ID is not constant, special parameter can be configured.
For applications in insulated vessels, it is recommended to insulate also the nozzle, ball-valve, flange and part of the instrument. This prevents condensation and build-up on the antenna and nozzle and increases the reliability and security for the measurement.
7.5.1 Floating roof tanks

In some floating roof applications, it may be beneficial, or even the only way, to use the radar to measure to the floating roof instead of the liquid. The sensor should be mounted perpendicular to the surface. In this application, the radar tracks the roof instead of the liquid. An offset should be entered in the radar to allow for the roof thickness.

The radar will track the level down to where the roof leg lands. When the legs have landed, the radar will show the position of the roof even if the level is significantly lower.

The radar level accuracy is limited to how well the roof is following the liquid. There are seal frictions that influence how freely the roof is moving up and down. In some cases, the roof can stick during filling and emptying and that could result in measurement errors. If a lot of snow or water is collected on the roof, the radar gauge could start to measure to the snow/water instead of the roof.

If the radar is installed in an external floating roof tank the radar needs to have a Federal Communications Commission (FFC) license. The radar gauge has an FCC part 15 license which is valid for a regular tank installation. In the external floating roof case, the radar gauge is in ‘open air’ and a FCC part 90; a license needs to be provided. The application is straightforward and can be made online. This paragraph is pertinent for the installations located on the United States of America territory or where the USA regulations are mandatory and where FCC regulation applies.

The radar needs a horizontal reflector installed on the roof if the roof is not flat. This is normally the case for external floating roof tanks where the pontoon has a slight angle. The reflector needs to be a minimum 50 mm × 50 mm (75 mm × 75 mm is generally used). The reflector should be installed in an area on the floating roof with as few metal obstructions as possible and horizontally mounted.

7.6 Calibration and configuration

Non-contact Radars are initially calibrated in factory with an initial dielectric value (e.g. 1.6).

- **Dry calibration:** Zero and Full scale values are adjusted manually. These scale values represents the minimum and maximum level to be measured. These settings can be made in situ or not.
- **Wet calibration:** wet calibration is necessary to take into account all the false echoes due to the internal vessel shape. The electronic record these false echoes. These false echoes are filtered and are no longer taken into account during the level measurement. This wet calibration should be performed with the actual low level so that all potential interfering reflections are detected.
8. Guided wave radar

8.1 Measurement principle

Guided wave radar (GWR) technology is based on the Time Domain Reflectometry (TDR) principle. Low power nanosecond-pulses are guided along a probe submerged in the process media. When a pulse reaches the surface of the material it is measuring, part of the energy is reflected back to the transmitter, and the time difference between the generated and reflected pulse is converted into a distance from which the total level or interface level is calculated.

The speed of travel of the pulse is impacted by the dielectric of the medium. This change in travel time is predictable and allows compensation for the measurement to be accomplished.

The reflectivity of the product is a key parameter for measurement performance. A high dielectric constant (DC) of the media gives better reflection and a longer measuring range.

![Figure 36 GWR Typical interface level reflection](image)

When an interface level of two immiscible layers should be measured, the first fluid should have the lower dielectric. The reflection from this first low dielectric fluid is weak. This permits to the rest of the signal to detect the interface between these two fluids. Less than 5% of the signal is reflected back to the transmitter for a fluid with a dielectric of 2 (e.g. oil). Interface measurement accuracy depends on the upper product dielectric and a distinct interface (low emulsion layer of few mm) between the two fluids.
8.2 Limitations

While guided wave radar works in many conditions, some precautions need to be taken with respect to probe choice. Several probe styles are available and the application, length, and mounting restrictions influence their choice. Unless a coax-style probe is used, probes should not be in direct contact with a metallic object, as that will impact the signal.

If the application tends to be sticky or coat, then only single lead probes should be used. Single lead probes are preferred when there is a risk of contamination (because coating can result in the product bridging across the two leads for twin versions or between the inner lead and outer pipe for the coaxial probes, and may cause erroneous level readings). For viscous or sticky applications, PTFE probes are recommended to facilitate product flow. Periodic cleaning may also be required. Maximum error due to coating is 1–10% depending on probe type, dielectric constant, coating thickness and coating height above product surface. The presence of oil-film on the single probe will not have any effect.

Some advanced GWRs on the market have advanced diagnostics, with the ability to detect build-up on the probe. This gives indication of how good the surface signal is compare to the noise, and when to clean the probe (predictive maintenance).

GWR can be used on cryogenic application (e.g. −196°C) with recommendation of coaxial probe. Proper insulation may be required to reduce ice formation on the upper part (e.g. insulate the nozzle).

GWR measurement in foamy applications depends on the foam properties: light and airy or dense and heavy, high or low dielectrics, etc. If the foam is conductive and dense, the transmitter may measure the surface of the foam. If the foam is less conductive, the microwaves may penetrate the foam and measure the liquid surface. This type of applications should be considered on a case by case basis. Depending on foam properties, GWR may detect the foam/liquid interface or the top of the foam or the top of the liquid.

GWR are not suitable for water–sand interface. Since the sand is embedded in water, which is a high dielectric media (DC = 80), the transmitter can only see the water. The same is true for all media that are dissolved in water.

Different parameters (factors) affect the echo and therefore the maximum measuring range differs depending on application according to:

- disturbing objects close to the probe
- media with higher dielectric constant gives better reflection and allows a longer measuring range
- surface foam and particles in the tank atmosphere may affect measuring performance
- heavy coating or contamination on the probe should be avoided since it can reduce measuring range and might cause erroneous level readings.

51
When interface will be measured, the criteria according to Figure 38 should be fulfilled:

- **Target applications**
  - Low (<3) dielectric constant of upper product
  - High (>20) dielectric constant of lower product

- **Difference between dielectric constants for the two products should be larger than 6**

- **Upper product DC**
  - Must be known and should be constant.
  - Must have a lower DC than the lower product.

### Figure 37 GWR interface level measurement

### Figure 38 GWR Interface measurement dielectric criteria
The maximum allowable upper product thickness/measuring range is primarily determined by the dielectric constants of the two liquids. An example of the maximum upper product thickness for the flexible single probe is presented in Figure 40. However, characteristics can vary between the different applications.

8.2.1 Emulsion/rag layer

Emulsions/foam above a few centimetres disrupt the interface measurement. The results vary with the fluid mix. In many cases, the interface is measured at the top of the emulsion layer. Emulsion layers above few centimetres cannot be measured with the GWR principle. This is due to the emulsion dielectric stochastic repartition and the emulsion bubble composition. If the emulsion layer is greater than few centimetres only the top of the upper layer can be detected.

Sometimes emulsion can be formed of a mixture of fine solids combined with emulsified oil and water, sometimes including multiple components. Stable liquid emulsion and solid particles trigger rapid emulsion layer growth. The more particles are present, the larger such an emulsion is. Although applications with emulsions are difficult for GWR measurement, the usage of a stilling well can help to achieve better product separation and therefore more accurate measurements.
Figure 41 GWR interface measurement in vessel with emulsion
8.3 Selection

GWR provides accurate and reliable interface measurements and can be used in a wide variety of applications. It is a top-down, direct measurement as it measures the distance to the product surface. GWR should be considered for clean liquid–liquid interface and/or clean liquid–gas interface.

GWR interface measurement with emulsion, foam, fluid buildup or crystallization is not possible (deposit causes false reading).

GWR level instrument accuracy is a function of the liquid dielectric constant. Care should be taken to determine the dielectric constants of the fluids being measured over their full range of possible compositions and operating conditions.

The vessel internals e.g. supports and reinforcement should not be at the vicinity of the level measurement device or in the radar path.

GWR requires a relatively flat fluid surface. If surface is turbulent then a Stilling Well should be considered.

For long probes, the lower probe end should be fitted with an additional stainless steel cylinder with fixing eye to ensure an adequate fixing to the bottom of the vessel.

GWR installed in a sensor cage or standpipe should never be in contact with the cage/standpipe internals. Centring disk may be used. The centring disk should provide isolation between the probe and the cage/standpipe internals.

GWR sensor cage/stand pipe measuring range should be carefully studied. For a side–side sensor cage/stand pipe the maximum measuring range should be between the middle (axe) of the upper and the lower tapping connection.

A key advantage of radar is that changes in pressure, temperature, and most vapour space conditions have no impact on the accuracy of its level measurements. Moreover, no compensation is necessary for changes in dielectric, conductivity, or density of the fluid.

Changing density is one of the major issue is when measuring level or interface using older technologies, such as displacers; they are more likely to happen due to changes in process or ambient conditions, and thus have more influence on the reliability and accuracy of density based technologies.

In addition, radar devices have no moving parts, so maintenance is minimal. GWR is easy to install and enables simple replacement of older technologies, even while there is liquid in the tank.

8.4 Installation

8.4.1 Direct measurements on the top of the tank (flanges connection)

Below are recommendations for the nozzle configuration and dimensions for flanged installations on top of the tank/vessel.
Chambers with a diameter less than 7.62 cm can cause problems with build-up and might make it difficult to avoid contact between chamber wall and probe. Chambers provide a fixed view of the level in a vessel. Thus, when the level drops below or rises above the chamber, it will not be seen in the chamber. The effective measurement range of a chamber is the area between the taps.

<table>
<thead>
<tr>
<th>Table 2 GWR nozzle diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recommended Nozzle Diameter (D)</strong></td>
</tr>
<tr>
<td><strong>Minimum Nozzle Diameter (D)</strong></td>
</tr>
<tr>
<td>**Maximum Nozzle Height</td>
</tr>
</tbody>
</table>

8.4.2 Chamber installation and sizing

The location of the chamber should be as close to area of measurement as possible. If the chamber is further away, the fluid inside it is less like the fluid in the vessel. More distance gives more time for the fluid to cool (or heat up in cryogenic applications). Cooler fluid will be more viscous and dense. More viscous fluid will not respond as quickly and in extreme cases, can completely plug the chamber. Larger connections between the vessel and the chamber will enhance flow-through of the fluid and allow fresh fluid to move through the chamber more easily and more closely resemble the material in the vessel.

If the density in the chamber is lower than the density of the fluid in the vessel, it may actually appear to ‘shrink’ and cause the level measurement to be lower in the vessel than it actually is, especially if fluid movement is stagnant.
8.4.3 Match product level in tank and chamber

Below are examples of cases that might occur in field conditions.

![Figure 43 GWR chamber installation and sizing](image)

![Figure 44 GWR Case 1 – Difference in product specific gravity (SG)](image)
Figure 45 GWR Case 2 – Lack of circulation in chamber

- **Day 1**: A finite amount of fluid is added, and separation occurs.
- **Day 2**: More fluid is added in vessel, but lack of circulation in chamber prevents interface from being the same.
8.4.4  Level and interface applications

Measurement of level and interface in a chamber should be avoided as the lack of fluid flow will not provide representative measurements. However, chambers are often used for interface measurements between oil and water. In cases where it is the only way to get a measurement, multiple connections to chamber will help to enhance fluid flow. The additional crossover connections should be located near the more critical measurement areas. In these applications, there should be good flow-through of both the top and bottom fluid for the interface measurement to be tracked. Care should be taken to avoid having a layer of fluid trapped in the chamber.

Interface measurements should assess the dielectric constant of both layers to properly configure the device for the intended level application. Specific configuration parameters might require adjustment once the device has been commissioned.

![GWR chamber with multiple connections](Image)

**Figure 46 GWR chamber with multiple connections**

8.4.5  Fully submerged interface applications

A submerged interface application is one where the upper portion of the probe is in oil or a similar fluid and the interface between the upper fluid and lower fluid is the desired measurement. Often this measurement is done with the GWR mounted in a chamber/cage. This is called a flooded chamber.

A single lead probe should always be used for this application as this provides the most distinct reference pulse. Ideally, there should be no air gap present at the top of the probe. However, air is often trapped in the chamber.

If there is an air pocket, then it creates an offset in the measurement reading due to the difference in the speed of travel of the microwaves in the air space compared to the upper fluid. For example, if the device is configured with oil as the upper fluid with dielectric constant of 2, the offset error will be 30% of the size of the air pocket (that is, a 15.7 in. (40 cm) air pocket creates a 4.7 in. (12 cm) offset error to the reading).

There are several options available to overcome the error introduced due to the air pocket:

- If process safety allows it, a vent can be included in the top of the chamber that allows the air to be removed. This vent can be piped back to process. A flushing ring can be installed between the GWR flange and the chamber flange to accommodate this.
If the air pocket is small and is within the upper blind zone of the device, Upper Null Zone can be configured to block any potential incorrect reading of the surface.
8.4.6 Interface measurements in vessels

The most common interface application in vessels implies measurements of both upper product level and interface level.

![Figure 49 GWR interface measurement in vessel](image)

Though not very common, fully submerged vessel interface applications can be possible too. A good example of such application are desalters and inverted interface measurements.

8.4.7 Inverted interface measurements

The previous examples cover situations when the upper product has a lower DC than the lower one. However, sometimes there are applications where product disposition is inverted: the high dielectric product lies on top of the low dielectric one, which makes top-down measurement impossible for GWR. In this case, the GWR mounting position is inverted so that it is installed at the bottom of the tank. For applications where there may be some solids or slushy deposits at the bottom of the vessel, it is advisable to put a flushing connection in the mounting nozzle to allow occasional cleaning.

![Figure 50 GWR interface measurement in vessel with lower DC upper](image)
Configuration routine is the same as for standard interface measurements using interface with submerged probe mode.

Dielectric constants have to be set according to product separation. Upper product means the one that is closer to the tank bottom.

When installing GWR on the tank bottom, there is no limit of probe types to be used. Flexible probes need to be attached to the tank roof. This can be done by following the same guidelines, provided for standard installations.

8.5 Calibration and configuration

The actual upper media DC value is known. The configuration needs to include the actual DC value (at factory or at site).

If the actual upper DC is not known in a range of 20% around the actual measure, the accuracy will be impacted.

Above this 20% value, it is recommended to perform a site/field calibration to improve the measurement accuracy.
9. Hybrid capacitance/GWR

9.1 Measurement principle

The measurement is based on a hybrid technology: capacitance and GWR. The respective measuring principles are described in section 6 [Capacitance] and section 8 [Guided wave radar]. The system is based on the GWR technology, whereas for interface applications this method is combined with a capacitive measurement. The two technologies were chosen because of the performance of capacitance technology with emulsion layers and the GWR’s performance for precise overall level.

The reference point R of the measurement is located at the process connection.

The Measuring Range

Rod Probe ≤ 4 m/13 ft
Rope Probe ≤ 10 m/33 ft
Coaxial probe ≤ 6 m/20 ft

Figure 51 Hybrid capacitance/GWR measurement principle

$R = \text{reference point of measurement}$

$E = \text{empty calibration (}= \text{zero})$

$F = \text{full calibration (}= \text{span})$

$LN = \text{probe length}$

$UP = \text{thickness upper medium}$

$D_L = \text{distance level complete}$

$L_L = \text{level complete}$

$D_I = \text{distance interface (distance flange / DC_I)}$

$L_I = \text{level interface (distance probe end / DC_I)}$
9.1.1 Interface with emulsion layer

If a clear interface layer exists, the hybrid system measures the overall level and the interface via the guided radar mode. In the background, the capacitive analysis always operates simultaneously and calculates the capacity value using the measured distances and the known capacitive conditions of the coaxial probe and derives the DC value of the oil layer from it. This measured DC value is used, in turn, for the time-of-flight correction in the interface measurement through the oil layer which makes it possible to measure interfaces. Even in large DC value fluctuations of the upper hydrocarbon layer.

In traditional guided radar probes, the emulsion layer causes a loss of signal of the interface surface but keep the upper layer level (e.g. oil). The hybrid capacitance/GWR automatically switches to the capacitive mode and provide the lower level (water).

In presence of emulsion, the hybrid capacitance/GWR measures the upper layer level and the lower conductive layer below the emulsion. The overall emulsion layer cannot be known.

9.2 Limitations

GWR and capacitance limitations also apply to the hybrid capacitance/GWR technology. In presence of emulsion, only the capacitance technology measures the presence of water.

The DC of the upper medium should be known and constant.
The DC of the upper medium may not be greater than 10.
The DC difference between the upper medium and lower medium should be >10.
The distance between the upper layer and the interface should minimum be 60 mm.
Conductivity of the upper medium: <1 μS/cm
Conductivity of the lower medium: >100 μS/cm
Cannot measure a media which lead to fouling or heavy build up on the probe.

9.3 Selection

For interface measurement, ideally coax probes or rod probes in a chamber/cage/stilling well are used.
Coax probes are suited to liquids with viscosities of up to approximately 500cst. Coax probes can measure most liquefied gases, as of a dielectric constant of 1.4. Installation conditions, such as nozzles, vessel internal fittings etc. have no effect on the measurement when a coax probe is used. A coax probe offers maximum EMC safety when used in plastic vessels.
Rope probes may be used in a chamber/stilling well, if there is sufficient head room to install a rod probe. This can exclude the rope or end-of-probe weight touches the wall of the tube (diameter large enough, precisely vertical tube).

9.4 Design

The hybrid capacitance/GWR should have the right probe for the appropriate level range for the application.
9.5 Installation

Rod/rope probes can be mounted in a stilling well or chamber/cage. In this case, the distance of the rod/rope probe and internal diameter of the chamber/cage/stilling well should be between 40 mm and 100 mm. The distance from the end of rod/rope probe to the bottom of the vessel should minimum be 10 mm.

Coax probe can also be used and be mounted at an arbitrary distance from the wall of the vessel.

Within the measuring range, the rod/rope/coax probe should not get into contact with the chamber/cage/stilling well wall. If required, centre disks should be used. Centre disks should not be located in the measuring range.

For long rope/coax probe an additional weight or a spring should be considered.

For underground vessels rod/rope/coax probe should be designed with large nozzle diameters in order to avoid reflections at the nozzle wall.

For non-metallic vessels coax probe is recommended.

For vessels with heat insulation, the electronic housing should be located outside the vessel insulation. This is to prevent the electronics from heating up as a result of heat radiation or convection.

The insulation should not exceed the points labeled ‘max’ in the figure below.

![Figure 52 Hybrid capacitance/GWR installation with heat insulation](image)

9.6 Calibration and configuration for interface level measurement

Calibration is performed in the factory with complete assembly. In situ calibrations (low and high range) are only used for recording the linearity protocol. In case the calibration values are different from the factory ones they should be set as a customized parameterization.

The actual upper media DC value should be known.

- Wet calibration: The probe can be calibrated for its full range, i.e. lower interface level (0% level calibration) and high interface level (100% level). Other intermediate values can also be performed.
  
  Low interface level simulation aims to suppress the false echo (for GWR measurement) and provide 0% level value for the capacitance part.
  
  High interface level simulation aims to provide the maximum range value for both GWR measurement and capacitance part.

- Dry calibration: The level capacitance can be simulated by entering the low and high level values. Capacitance units will calculate automatically the capacitance variation image based in the factory calibration for ≥100 µS/cm.
10. Nucleonic

10.1 Measurement principle

The nucleonic measuring principle is based on the attenuation of gamma radiation as it penetrates materials. The radioactive isotope (gamma source) is installed in a container, also referred to as shielding, which emits the radiation only in one direction.

The source container and the transmitter detecting the radiation are usually mounted on opposite sides of a vessel or pipe.

The emitted radiation (e.g. gamma rays) passes through the vessel walls and the medium contained in the vessel.

The actual measuring effect results from the absorption of the radiation by the medium.

The intelligent transmitter calculates the level, density or the concentration of the medium from the radiation received.

The higher the level or the density of the medium in the vessel the lower the intensity of the radiation received.

In conventional level and density measurements 137 Cesium and 60 Cobalt are commonly used. 241 Americium or 244 Curium may be used for heavy element measurement in a medium consisting of lighter elements.

10.1.1 Continuous level measurement/full absorption

In this measurement principle, the radiation is fully absorbed. The radiation difference between the source and the detector varies given the image of the level. The radiation activity is calculated from the pulse rate received.

Typically the pulse rate (radiation level) at 100% level is zero, meaning the gamma rays are completely absorbed by the medium (full absorption). For example, at 50% of the full range level, only the upper part of the detector receives the radiation. Consequently the pulse rate increases.
10.1.2 Interface measurement

In nucleonic interface measurement, the source may be inserted in an enclosed dip tube with a cable extension which excludes any contact of the source with the medium.

Depending on the measuring range and the application, one or several detectors are mounted on the outside of the vessel.

The intelligent transmitter measures the average density of the medium between the source and the detector from the radiation received.

A direct relationship to the interface layer can then be derived from this density value.
10.1.3 Density profile

The most exact information on the oil/water emulsion layer is achieved by a multi-detector solution, the so-called profiling.

Several transmitters are arranged on the vessel on a vessel wall or inside the vessel. Each detector measures an absorption image of the density.

The measuring range is subdivided into zones and an applicable density value is calculated for each zone. The density image is analyzed via an algorithm and visually provided on a monitor.

![Figure 55 Nucleonic density profile principle](image)

10.2 Limitations

In many countries, the use of nucleonic systems requires the possession of a license due to the potential hazard to personnel. In order to be in accordance with local, state, and federal regulations extensive paper work might be required. The installation is regulated at the local, state, and on the federal level. Sometimes a periodic wipe testing has to be conducted.

Government regulations may require the appointment of a radiation safety officer responsible for enforcing regulations at the owner’s site, including periodic inspections and tests of all nuclear gauges.

Depending on instrument design some applications may require extremely large sources, which can increase delivery times, licensing requirements, and may require special mounting consideration.

Sensitivity to X-ray (NDT (non-destructive testing) methods) can cause a false trip to a running unit.

Nuclear devices can be difficult to calibrate accurately. It may be required to empty and fill the vessel to zero and span the device to obtain the desired calibration accuracy. The hard part is normally related to how practical/easy it is to get the required process conditions for calibration.

Due to the fact that the source containers use lead to shield the radiation, the containers can be very heavy and a crane might be required for installation.

The use of nucleonic measurement principles for fast control loop or safety application should be evaluated based on required response time (as the profile is reconstructed from density profile using several sources/detectors and calculation units).
Depending on distance and position of source to sensor, small levels of foam can have significant effect on the measurements. This is due to the density difference between foam end gas vapours.

Interface measurement/density profile may be used if the emulsion layer thickness or the density profile needs to be measured. However if specific values ρwater and ρoil of an emulsion have been used during the calibration stage, then the operated values of ρwater and ρoil should be the same otherwise it will not be possible to characterize the other layers. For example that if the oil density varies from 900 kg/m³ (calibration value) to 800 kg/m³ and if 800 kg/m³ have been ‘declared’ as ‘emulsion’ then the new oil density will be seen as an emulsion.

10.3 Selection

Nucleonic level measurement is used in situations where other instruments cannot be placed in a vessel or reactor due to very corrosive or extremely adhesive products, in reactors or furnaces at very high pressures and/or temperatures.

10.4 Design

A nucleonic system needs to be engineered according to the application requirements. The source activity required is calculated based on the vessel design (wall thickness, wall material, etc.) as well as the installation possibilities.

Additional aspects to be considered are: measuring range, the density of the process medium, expected thickness and density of build-up formation (if any), obstacles in vessel and the ambient temperature at the detector.

In terms of an interface measurement or density profile system engineering is required to determine the correct position of the nuclear source. If the source needs to be placed inside a dip tube, an appropriate nozzle needs to be available. The dip tube can be curved if required to allow the source to be inserted to the correct point even if no suitable spare process connection is available.

For interface or profiler applications, if the measurement range exceeds 1.5 m more than one source is required.

Proper shielding needs to be considered, depending on the expected dose rates (empty vessel). Particular attention should be paid to the temperature of the detectors. Typically detectors can operate in ‘standard’ process conditions. Therefore, for some applications, a cooling system may be required. If it is the case the cooling systems should be included in the design and submitted to the product manufacturer for approval. This cooling system should minimum comprise header from the cooling skid, suitable tapping point with isolation valves between header and detectors, a water cooling skid (centrifugal pump, air cooler, expansion bottle, temperature and pressure gauges as required, temperature, pressure and flow transmitters as required).

10.5 Installation

This level measurement may have the source(s) and the detector(s) internally or externally mounted (see Figures 56 to 59).
This mounting arrangement should be studied taking into account fluids, process connections, vessel material, the source and detector distance and angles between the source and the detector. This study should highlight the mounting arrangement pro and cons.

Equipment mounted externally or internally might require additional supporting structures.

The applicable sketch should be developed based on the vessel shape and material, the fluid features (including build-up), the operation and maintenance requirements (e.g. on site calibration). The sizes and distances stated in the hereunder should be studied.

**Figure 56** Nucleonic internal source and detector principle in two separated dip pipes example

**Figure 57** Nucleonic internal source and detector principle in one dip pipe example
10.6 Calibration and configuration

A nuclear system always needs to be calibrated in the field. For interface or profile applications, it is recommended to use two different media for the calibration.

A one or two point calibration method can be used to setup an interface/profiling application.

A one point calibration (e.g. with water) is more convenient if a vessel can only be filled with one defined homogeneous media. However, the interface measurement accuracy will depend on the difference between the lower and upper fluid density.

One point calibration
Calibration process

- perform background calibration (vessel absorption)
- switch OFF the radiation. Perform water (other media are possible if the density is known) calibration (1. Point): Ensure that the vessel is filled with water only. The water level should be at least at the height of the upper detector. Switch ON the radiation.
- switch OFF the radiation. Perform oil (other media are possible if the density is known) calibration (2. Point): Ensure that the vessel is filled with oil. The oil level should be at least at the height of the upper detector. Switch ON the radiation.
11. Magnetic Level Indicator

11.1 Measurement principle

The Magnetic Level Indicator (MLI) is a simple, rugged instrument designed to indicate level or interface. It indicates level using a float magnetically coupled to an index or a column of rotating flaps. It is ideal for aggressive media stored in vessels when the PTFE lining option is used.

The float is equipped with a ring system of permanent magnets for transmission of liquid level to the indicator. The indicator is linked magnetically to the magnet system in the float.

For the purpose of design, the minimum level in the measuring tube is given by the lower lateral flange connection axis i.e. liquid level zero is the centreline of the lower connecting flange.

Magnetic level indicators (MLI) are preferred Level Indicator (compared with glass or reflex indicators) because of safer performance against external explosions and high pressure application.

There is a difference between the true liquid level and the indicator position because:

- the float is immersed to a certain depth depending on the product density and float type
- the float magnets are positioned below the float centreline in order for the float to have good stability.

The scale is delivered correctly set up for measuring the product specified in the order. The red reference mark at the top of the measuring tube (item 1 in the diagram below) shows where the top of the scale should be clamped for the indicator to give an accurate reading of liquid level. No further adjustment is necessary when the gauge is commissioned.

Notes:

1. If there is a large change in product density, a product other than the one specified in the order is measured or a different float is installed, the scale on the MLI may require adjusting to give an accurate reading.

2. Magnetostrictive Level Transmitter may be considered for giving the capability to transmit a level measurement signal remotely.

11.2 Limitations

If the user wishes to use the MLI to measure another product, then the following points should be noted:

- the depth of immersion of the float increases as product density decreases. This depth is also dependent on the float model and material used (AISI 316L, AISI 316Ti or titanium)
- the top of the float should be no more than 35 mm above the product surface to ensure reliable floatability and accurate measurement
- ensure that the float and chamber are designed according to the design pressure and temperature.
The chamber should be regularly drained down to prevent the build-up of debris and cleaned. Floats should be inspected to ensure they are not damaged, corroded or pitted. The rotating flaps should be lubricated and checked, as often they can stick causing an incorrect and misleading level.

11.3 Selection

MLI should be suitable for interface level measurement if specific gravities differ significantly and the change in specific gravity due to composition or temperature cannot affect the reading. It is allowed that the difference between specific gravities is greater than 0.1.

MLI instruments should not be used in severely turbulent, dirty, foaming, fouling service or in case of presence of solid particles in the fluid (e.g. sand). These conditions lead to unreliable measurements from displacement level instruments.

MLI should not be used for liquid-liquid interfaces when the two fluids form an important emulsion (above a few centimetres) or do not have a clean interface.

MLI should not be used in liquid-liquid or liquid–gaseous services where either the upper or lower fluid specific gravity is not relatively constant.

11.4 Design

MLI should be made of stainless steel or other material compatible with the process fluid.

MLI should have the height according to the level range for the application. The range of measurement is the C-C length.

Floats are selected in accordance with the liquid density.
11.5 Installation

The installation should be reviewed and any requirements for trace heating or insulation incorporated into the design and installation of the measuring tube.

Operating procedures should prevent rapid pressurization of the float chamber. Damage and failure of the float can occur if the chamber is pressurized quickly. The float can be rammed to one end of the chamber.

Float stops should be provided at both ends of the chamber. (This requirement from ATEX applications, typically fabricated using a high quality spring fitted with a carbon or PTFE buffer, depending on design process conditions.)

11.5.1 Mechanical installation requirements

The effective pressure of the installation (the maximum permitted by the pressure limiting valve) should never be greater than the maximum permitted pressure Ps of the instrument nameplate.

The application should be compatible with the fluid and conform to ageing characteristics of the fluid used and the measurement environment.

The external pressure (Pext) should be equal to atmospheric pressure (Patmos).

1 – Tank

2 – Liquid product

3 – MLI

Figure 62 MLI Mechanical installation requirement

11.5.2 Mounting on the vessel

The chamber/cage level indicator should be installed vertically on the vessel.

When installing the chamber/cage level indicator with or without the electrical level transducer system, make sure that any magnetic fields generated by other equipment will not affect measurements.
Selected bolts and gaskets should correspond to the pressure rating of the connecting flange and the operating pressure. The process connections (flanges) should fit properly, i.e. they should be centred, parallel and bolted in a professional way, in order to avoid unnecessary mechanical stress on the installation.

The vessel should be free of contaminants. It is recommended to install isolation and vent/drain elements, e.g. cocks, valves, etc. between the vessel and chamber/cage level indicator to allow the chamber/cage level indicator to be cleaned independently of the vessel. The drain plug in the bottom flange should also be replaced by a drainage cock with discharge line.
11.6 Calibration and configuration

Calibration should be performed at product manufacturer premises and verified prior to the commissioning activities.

Correcting the scale position to accurately read true liquid level (Process conditions changes)

The scale* can be corrected using the following procedure:

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Find the float immersion depth “c”</td>
</tr>
<tr>
<td></td>
<td>Subtract the dimension “a”, float base to magnet centreline (given on the float dimensioned, from “c” to get the dimension “b”, scale correction factor.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
<td>c – a (difference between liquid level and indicator position due to product density)</td>
</tr>
<tr>
<td>c</td>
<td>float immersion depth (a function of product density)</td>
</tr>
<tr>
<td>a</td>
<td>distance from centreline of magnet system to the float base</td>
</tr>
<tr>
<td>1</td>
<td>float</td>
</tr>
<tr>
<td>2</td>
<td>Follower magnet of indicator (or limit switch)</td>
</tr>
<tr>
<td>3</td>
<td>Position of magnets mounted in the float</td>
</tr>
</tbody>
</table>

3  Loosen the two clamp collars holding the measuring scale onto the measuring tube using a screwdriver or 8 mm wrench.

4  Bring the zero point on the scale into line with the centreline of the bottom lateral process connection.

4a  Undo top collar

---

1  Measuring scale

2  Measuring tube

3  Top measuring scale collar
12. Manual measurement

Although the scope of the document is about fixed installed measuring instruments, manual measurements should be at least discussed briefly. Manual measurements are still quite often used as they are perceived as ‘low cost’ (at least initial), do not require cabling or power and are often used for during commissioning, or verification of installed instrumentation.

12.1 Measurement principle

There are three mains manual measurement principles used:

- tape, ruler or dip stick
- sight glass
- portable electronic.

Both of these manual methods make use of a graduated measurement tape, ruler or dipstick, to read the level and/or interface.

12.1.1 Tape, ruler and dipstick

This measurement is typically used on large tanks.

Figure 63 Typical gauge tapes, bobs and a water gauge bar (Source: API MPMS Ch. 3.1A)  
Figure 64 Photo of typical dip tape as use on bulk storage tanks
A ruler or dipstick is typically used for relative small tanks. A practical limit is 2 to 3 metres height max. In some area’s/countries also so called ‘slip tube’ gauges are used for on LPG rail tankers.

NFPA 58 describes slip tube gauge as a “A variable liquid level gauge in which a relatively small positive shutoff valve is located at the outside end of a straight tube, normally installed vertically, that communicates with the container interior.” A slip tube is basically a ‘dip stick’.

On clear liquids and very light products which easily evaporate, including water, often a coloring paste is used. The paste changes color when in direct contact with the liquid.

For water detection which is often called ‘water-finding’ rule to detect a level is recommended. Water finding rules are typically made of brass with alternating transparent plastic sections, which allows seeing where the paste has discolored when measuring water in opaque oils

12.1.2 Sight glass

For closed tanks, and products which are toxic, easily evaporate or are flammable, often a sight glass is used. The sight glass is typically installed as part of a ‘chamber/cage’. It can either be a transparent piece of piping or a metal enclosure with typically a hardened flat glass view pane.

The tank connections often have block valves, which allow maintenance on the sight glass and sight glass body. Some sight glass designs also incorporate drain valves which allows cleaning (‘flush’) the system.
Reflex gauges are a special form of sight glass gauges, and use optical refraction and reflection for an improved visibility of interfaces in and between vapour/gas and liquid zones.

Is some specific areas and equipment (steam generators, boilers, power generation), the use of sight glass type level gauges may also be mandatory to fulfill the design code (e.g. ASME I).

Sight glass may also be useful where direct vision of the fluid is relevant.

12.1.3 Portable electronic gauging

Portable electronic gauging can measure the level of ullage and the oil–water interface. Portable electronic gauging is suitable for open and closed applications. Closed gauging operations will generally require the portable electronic gauging to be used in conjunction with a compatible vapour lock valve.
Representative measurements of the temperature of the tank contents may also be measured with the portable electronic gauging. This temperature measurement permits to convert the observed volume to a standard volume measurement.

### 12.2 Limitations

#### 12.2.1 Tape, ruler and dipstick

Tape, ruler or dipstick can only be used when the tank is not pressurized and the tank contents are considered to be safe (i.e. not toxic, dangerous and do not pose an environmental issue).
12.2.2 Sight glass

Sight glasses cannot be used for tanks containing sediment or solids, as the connection might become blocked.

Use of sight glasses can be considered for interface measurement also, provided the interface layer is clearly visible.

Sight glass installation is also possible on pressurized tanks but sometimes perceived as a safety risk.

On tanks which also contain solids, the reading of the sight glass can be unreliable as result of blockage. For these applications strict procedures for periodic flushing the sight glass and connections should be considered.

Sight glass systems have the limitation of where the level can be between glasses and in the ‘brass’ area and hence it is difficult to understand where the level is.

Sight glasses require regular maintenance and cleaning. The presence of some hydrocarbon liquids can cause staining and this can make it difficult to ascertain where the true level actually is placed.

12.2.3 Portable electronic gauging

Safety and environmental regulations may restrict tank gauging operations which can result in the release of hydrocarbons or other volatile organic compounds into the atmosphere. In these circumstances, it will not normally be feasible to use traditional open gauging procedures via an open gauge hatch or gauging access point.

![Figure 74 Portable electronic gauging system with vapour lock valve](image-url)
12.3 Selection

For all toxic, pressurized and dangerous products, ‘closed’ solutions are preferred.
If manual methods are to be used, the safe use should be covered by procedures and formal training.

12.4 Calibration and configuration

For applications where the accuracy is of importance, the graduated scale on tape, dip stick or sight glass can be calibrated.

It is important to realize that it is always critical to use the correct datum point on the particular tank. This datum point can be a ‘dip’ plate on the bottom or a clear marked mechanical provision on or in the tank nozzle.

Sight glasses can be adjusted by shifting the graduated scale.

The portable electronic gauging sensor is calibrated once at the factory and does not require subsequent calibration.
Annexes

Annex A  Pressure/temperature influences

A.1 Wave radar

High pressures/temperatures reduce the propagation velocity of the measuring signals in the gas/vapour above the liquid interface to be measured. The result of the high pressure/temperature is a systematic measuring error. Table 3 gives several measuring errors for different gases/vapours.

<table>
<thead>
<tr>
<th>Gas layer</th>
<th>Temperature °C</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T °F</td>
<td>1 bar (14.5 psi)</td>
</tr>
<tr>
<td>Air</td>
<td>20</td>
<td>0.00 %</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>-0.01 %</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>-0.02 %</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>20</td>
<td>-0.01 %</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>-0.02 %</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>-0.02 %</td>
</tr>
</tbody>
</table>

Table 3 Example of measuring error on wave radar with high pressure/temperature

These errors may be compensated with two main methods:

- compensation with external pressure and temperature sensors
- compensation with a reference signal.

Compensation with external pressure and temperature sensor is achieved by calculation with external pressure and temperature sensors.

Compensation with a reference signal means that the actual wave velocity is measured by calculating a reference reflection between two known points a known distance (Lref) and relevant transit time.

\[ L_{\text{ref}} = \text{Actual Velocity} \times \text{Transit time of this Lref.} \]

Having this Actual Velocity in the media, the distance can be calculated from the actual reflection time measurement. The Lref should be upper the higher maximum interface level with a margin (e.g. 150 mm in Figure 75).
**A.2 Nucleonic**

The attenuation of gamma rays depends on the distance between source and detector as well as the density along the beam path. Pressure and temperature variation affect the gas/vapour density. Due to this change of gas/vapour density, the gamma source count rate is impacted and therefore the level. The pressure/temperature variation is not linear consequently actual pressure and temperature should be measured and compensated.

To compensate the influence of the vapour density the attenuation factor should be calculated regarding the vapour density.
Figure 76 Example of vapour density compensation
Annex B  Pressure and temperature ranges

Table 4 gives typical pressure and temperature ranges. Process actual data should be checked against the Product Manufacturer particular technology.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Min</th>
<th>Max</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP (impulse lines)</td>
<td>Vessel Limits</td>
<td>-0.975</td>
<td>450</td>
<td></td>
</tr>
<tr>
<td>DP (diaphragm seals)</td>
<td>-75</td>
<td>600</td>
<td>-0.975</td>
<td>400</td>
</tr>
<tr>
<td>DP (Electronic DP)</td>
<td>-75</td>
<td>600</td>
<td>-0.975</td>
<td>400</td>
</tr>
<tr>
<td>Displacer (buoyancy)</td>
<td>-60</td>
<td>450</td>
<td>-1</td>
<td>200</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td>-40</td>
<td>90</td>
<td>-0.25</td>
<td>3</td>
</tr>
<tr>
<td>Capacitance</td>
<td>-200</td>
<td>400</td>
<td>-1</td>
<td>150</td>
</tr>
<tr>
<td>Non-Contact Radar</td>
<td>-200</td>
<td>450</td>
<td>-1</td>
<td>160</td>
</tr>
<tr>
<td>Guide wave Radar</td>
<td>-200</td>
<td>400</td>
<td>-1</td>
<td>400</td>
</tr>
<tr>
<td>Hybrid Capacitance/GWR</td>
<td>-50</td>
<td>200</td>
<td>-1</td>
<td>40</td>
</tr>
<tr>
<td>Nucleonic</td>
<td>Vessel Limits</td>
<td>Vessel Limits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnetic Level Indicator</td>
<td>-200</td>
<td>500</td>
<td>0</td>
<td>400</td>
</tr>
<tr>
<td>Manual Measurement</td>
<td>0</td>
<td>350</td>
<td>-1</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 4 Typical pressure/temperature ranges
Annex C Interface Measurement Selection Guidance – Automatic level measurement

Table 5 gives some guidance related to the oil–water interface level measurement for a single technology. However, it is important to understand the need of the measurement. For some application several technologies may be used to fix a need which cannot be solved by one technology only. Table 5 highlights some use cases but does not supersede the scope and limitation given in this recommended practice.

<table>
<thead>
<tr>
<th></th>
<th>DP</th>
<th>Displacer</th>
<th>Radar</th>
<th>GWR</th>
<th>Capacitance</th>
<th>Hybrid Capacitance/GWR</th>
<th>Nucleonic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil–gas Interface</td>
<td>Suitable</td>
<td>Suitable</td>
<td>Suitable</td>
<td>Suitable</td>
<td>Not Suitable</td>
<td>Suitable</td>
<td>Suitable</td>
</tr>
<tr>
<td>Clean Oil–water interface</td>
<td>Suitable</td>
<td>Suitable</td>
<td>Not Suitable</td>
<td>Suitable</td>
<td>Suitable</td>
<td>Suitable</td>
<td>Suitable</td>
</tr>
<tr>
<td>Oil–water interface with an important emulsion layer</td>
<td>Not Suitable Note 1</td>
<td>Not Suitable Note 1</td>
<td>Not Suitable</td>
<td>Not Suitable</td>
<td>Partially Suitable (Detect below the emulsion – around 80% of water)</td>
<td>Partially Suitable (Detect below the emulsion – around 80% of water and above the oil)</td>
<td>Suitable</td>
</tr>
<tr>
<td>Liquid–liquid interface with a little emulsion layer (few cm)</td>
<td>Suitable (loss of accuracy)</td>
<td>Suitable (loss of accuracy)</td>
<td>Not Suitable</td>
<td>Not Suitable</td>
<td>Suitable</td>
<td>Suitable</td>
<td>Suitable</td>
</tr>
<tr>
<td>Solid deposit, water, emulsion, oil and foam</td>
<td>Not Suitable</td>
<td>Not Suitable</td>
<td>Not Suitable</td>
<td>Not Suitable</td>
<td>Not Suitable</td>
<td>Not Suitable</td>
<td>Suitable</td>
</tr>
</tbody>
</table>

Note 1: The emulsion layer cannot be measured. The average density between the upper and lower density fluid may represents the emulsion density

Remark: All measurement may be challenged in the presence of dirty fluids (e.g. build-up). Product often provides build-up compensation functions.

Table 5 Interface Measurement Selection Guidance
Annex D  Symmetric and asymmetric capillaries

Symmetric capillary

1. Seal Effect: If the ambient temperature increases the capillary volume $V$ will tend to exert forces on the DP seal (both sides).

   If both capillary have the same features (volume, seal thickness, fill fluid and length) are the same, all the resulting forces on the DP seal will be equal to zero (black DP seal position figure below).

2. Hydrostatic Pressure: The hydrostatic pressure figure below is $P = \rho \times g \times D$ (where $\rho$ and $g$ are constants). For the increase in ambient temperature, the density $\rho$ will decrease.

   This means the hydrostatic pressure $P$ will decrease also. This will create an upper force (against the gravity force).

   The resulting (final) DP seal position is shown in red figure below.

   ![Figure 77 Symmetric capillary](image)

Asymmetric Capillary

Hypothesis: The volume $V_1 << V$ ($V_1$ is negligible)

1. **Seal Effect:** If the ambient temperature increases the capillary volume $V$ will tend to exert forces on one side of the DP seal (blue DP seal position Figure 78).

2. **Hydrostatic Pressure:** The hydrostatic pressure in Figure 78 is $P = \rho \times g \times D$ (where $\rho$ and $g$ are constants). For the increase in ambient temperature, the density $\rho$ will decrease.
This means that the hydrostatic pressure $P$ will decrease also. This will create an upper force (against the gravity force). This will tend to compensate the seal effect force.

The resulting (final) DP seal position is shown in blue in Figure 78.

![Figure 78 Asymmetric capillary](image)

This asymmetric resulting force is inferior to the symmetric resulting force.

**Limitation**

Tall vessels and towers have posed a significant measurement challenge. In particular, long vertical tap-to-tap distances require extended lengths of capillary to facilitate the installation. As the tap-to-tap distance grows, the resulting head pressures within the capillary become too great to ‘tune’ out. Time-response can be sub-optimal on tall vessels and towers as the distance the pressure signal propagates through is substantially greater. Overall, as the length of capillary attached to the transmitter low side increases, an accurate measurement becomes increasingly more difficult to achieve.
# Table of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Pressure vessel mounting principle</td>
<td>9</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Measuring range</td>
<td>10</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Interface level with no emulsion representativeness</td>
<td>14</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Interface level with emulsion representativeness</td>
<td>14</td>
</tr>
<tr>
<td>Figure 5</td>
<td>DP measurement</td>
<td>18</td>
</tr>
<tr>
<td>Figure 6</td>
<td>DP Impulse</td>
<td>20</td>
</tr>
<tr>
<td>Figure 7</td>
<td>DP Level vs density measurement</td>
<td>21</td>
</tr>
<tr>
<td>Figure 8</td>
<td>SP Process connection with diaphragm</td>
<td>24</td>
</tr>
<tr>
<td>Figure 9</td>
<td>DP Steam heating facilities</td>
<td>24</td>
</tr>
<tr>
<td>Figure 10</td>
<td>DP SM or RTJ diaphragm flanges</td>
<td>25</td>
</tr>
<tr>
<td>Figure 11</td>
<td>DP flushing/draining</td>
<td>25</td>
</tr>
<tr>
<td>Figure 12</td>
<td>DP capillary protection</td>
<td>26</td>
</tr>
<tr>
<td>Figure 13</td>
<td>DP Capillary arrangement</td>
<td>26</td>
</tr>
<tr>
<td>Figure 14</td>
<td>Displacement Measurement</td>
<td>28</td>
</tr>
<tr>
<td>Figure 15</td>
<td>Displacement in situ calibration</td>
<td>31</td>
</tr>
<tr>
<td>Figure 16</td>
<td>Ultrasonic Liquid Measurement Arrangement</td>
<td>33</td>
</tr>
<tr>
<td>Figure 17</td>
<td>Ultrasonic calibration</td>
<td>34</td>
</tr>
<tr>
<td>Figure 18</td>
<td>Capacitance measurement principle</td>
<td>35</td>
</tr>
<tr>
<td>Figure 19</td>
<td>Capacitance operating range</td>
<td>36</td>
</tr>
<tr>
<td>Figure 20</td>
<td>Capacitance installation</td>
<td>38</td>
</tr>
<tr>
<td>Figure 21</td>
<td>Capacitance calibration</td>
<td>39</td>
</tr>
<tr>
<td>Figure 22</td>
<td>Radar measurement principle</td>
<td>40</td>
</tr>
<tr>
<td>Figure 23</td>
<td>Radar FMCW principle</td>
<td>41</td>
</tr>
<tr>
<td>Figure 24</td>
<td>Radar pulse principle</td>
<td>41</td>
</tr>
<tr>
<td>Figure 25</td>
<td>Radar with 6.3 GHz</td>
<td>42</td>
</tr>
<tr>
<td>Figure 26</td>
<td>Radar with 26 GHz</td>
<td>42</td>
</tr>
<tr>
<td>Figure 27</td>
<td>Radar with 26 GHz</td>
<td>43</td>
</tr>
<tr>
<td>Figure 28</td>
<td>Radar measuring the level through the plastic vessel</td>
<td>43</td>
</tr>
<tr>
<td>Figure 29</td>
<td>Radar antenna shape</td>
<td>45</td>
</tr>
<tr>
<td>Figure 30</td>
<td>Radar Direct top vessel Installation</td>
<td>46</td>
</tr>
<tr>
<td>Figure 31</td>
<td>Radar alignment</td>
<td>46</td>
</tr>
<tr>
<td>Figure 32</td>
<td>Radar socket or nozzle radar installation</td>
<td>47</td>
</tr>
<tr>
<td>Figure 33</td>
<td>Radar full port ball valve</td>
<td>47</td>
</tr>
<tr>
<td>Figure 34</td>
<td>Radar installation using stilling well</td>
<td>48</td>
</tr>
<tr>
<td>Figure 35</td>
<td>Radar installation using chamber/cage tube</td>
<td>48</td>
</tr>
<tr>
<td>Figure 36</td>
<td>GWR Typical interface level reflection</td>
<td>50</td>
</tr>
<tr>
<td>Figure 37</td>
<td>GWR interface level measurement</td>
<td>52</td>
</tr>
<tr>
<td>Figure 38</td>
<td>GWR Interface measurement dielectric criteria</td>
<td>52</td>
</tr>
<tr>
<td>Figure 39</td>
<td>GWR Maximum dielectric constant vs technology</td>
<td>53</td>
</tr>
<tr>
<td>Figure 40</td>
<td>GWR Maximum upper product thickness</td>
<td>53</td>
</tr>
<tr>
<td>Figure 41</td>
<td>GWR interface measurement in vessel with emulsion</td>
<td>54</td>
</tr>
<tr>
<td>Figure 42</td>
<td>GWR possible error chambers measurement</td>
<td>56</td>
</tr>
</tbody>
</table>
Figure 43 GWR chamber installation and sizing

Figure 44 GWR Case 1 – Difference in product specific gravity (SG)

Figure 45 GWR Case 2 – Lack of circulation in chamber

Figure 46 GWR chamber with multiple connections

Figure 47 GWR fully submerge air pocket

Figure 48 GWR fully submerge air pocket echo

Figure 49 GWR interface measurement in vessel

Figure 50 GWR interface measurement in vessel with lower DC upper

Figure 51 Hybrid capacitance/GWR measurement principle

Figure 52 Hybrid capacitance/GWR installation with heat insulation

Figure 53 Continuous level measurement/full absorption principle

Figure 54 Nucleonic Interface Measurement Principle

Figure 55 Nucleonic density profile principle

Figure 56 Nucleonic internal source and detector principle in two separated dip pipes example

Figure 57 Nucleonic internal source and detector principle in one dip pipe example

Figure 58 Nucleonic internal source/detector and external detector/source example

Figure 59 Nucleonic external source and detector example

Figure 60 Nucleonic one point calibration

Figure 61 Nucleonic two points calibration

Figure 62 MLI Mechanical installation requirement

Figure 63 Typical gauge tapes, bobs and a water gauge bar (Source: API MPMS Ch. 3.1A)

Figure 64 Photo of typical dip tape as use on bulk storage tanks

Figure 65 Example of dip stick as used for underground storage tanks

Figure 66 Example of dip opening of foreground station (petrol station)

Figure 67 Sight glass on fuel tank

Figure 68 Examples of various forms and shapes of sight glasses

Figure 69 Example of sight glass construction for pressurized application

Figure 70 Sight glass installed on LPG horizontal bullet tank

Figure 71 High pressure sight glass with graduated scale

Figure 72 Portable electronic gauging system with vapour lock valve

Figure 73 Necessary safety precautions (PPE) on toxic products

Figure 74 Portable electronic gauging system with vapour lock valve

Figure 75 Example of high pressure/temperature compensation with reference signal mounting arrangement

Figure 76 Example of vapour density compensation

Figure 77 Symmetric capillary

Figure 78 Asymmetric capillary
Table of Tables

Table 1 Example of product dielectric constant ................................................................. 43
Table 2 GWR nozzle diameter ............................................................................................ 56
Table 3 Example of measuring error on wave radar with high pressure/temperature ......... 84
Table 4 Typical pressure/temperature ranges .................................................................... 87
Table 5 Interface Measurement Selection Guidance .......................................................... 88
Measurement of single and multi-layer level in the hydrocarbon processing industries is commonly needed, but doing so accurately is often challenging. There are a great diversity of situations which require such level measurement, ranging from pure fluid to viscous, muggy and corrosive fluids.

This Recommended Practice covers the selection and installation of instruments used for single and multi-layer level measurement that are encountered in upstream hydrocarbon facilities.