

# Fundamentals of Hydrostatic Level Measurement

For many years, hydrostatic pressure measurement has been the most important measuring principle in continuous level measurement. This article presents the fundamentals of hydrostatic level measurement in a practical and understandable format.

## The importance of hydrostatic level measurement

Level measurement has seen considerable change over the past decades - from purely mechanical level measurement through to complex electronic sensors using various measuring principles. The large number of different technologies for measuring level (such as hydrostatic, reed chain, magneto-resistivity, radar, ultrasound, optical) today offers the user the possibility to choose the most suitable sensor technology for his individual application.

In continuous level measurement, hydrostatic pressure (also known as hydrostatic level measurement) is the principal sensor technology and measuring principle, with a market share of approximately 40%<sup>1</sup> by sales volume.

## What is meant by hydrostatic?

Hydrostatic pressure sensors are used for the measurement of level or filling height of a liquid. Hydrostatic pressure measurement is suited for level measurement due to the hydrostatic effect of non-flowing fluids. This physical principle describes the effect of the weight force of a stationary liquid on a measuring point. This weight force is usually described as "hydrostatic pressure".

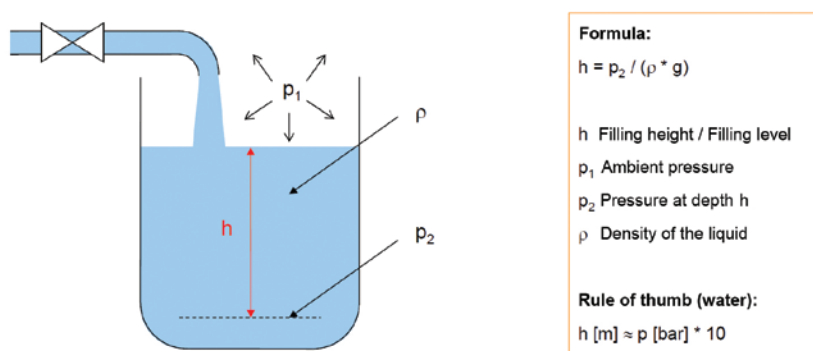


Figure 1: Level measurement in open, vented tanks and vessels.

The most important condition for hydrostatic level measurement is what is called the "hydrostatic paradox". This means that, regardless of the shape and volume of a vessel, the hydrostatic pressure at the measuring point of a tank or vessel is proportional only to the filling height. Thus, the hydrostatic pressure at the measuring point is solely proportional to the absolute filling height, and not to the filling volume.

Since the hydrostatic pressure is not dependent upon the volume or the shape of a vessel, it can be used directly for the measurement of the fill level, but must be further processed to "measure" the fill volume. From the measured level, using a 'tank linearization table', the actual fill quantity present in the vessel can be calculated. A tank linearization table documents, for different pressure values, the respective fill quantity present in the vessel. From the values documented, a curve can then be derived which presents the user a corresponding fill volume for every hydrostatic pressure measured. This calculation is usually carried out in the PLC, so that the operator has a display of the actual fill quantity present in the vessel, directly on-screen.

In order to determine the fill quantity from the hydrostatic pressure with a high accuracy, the pressure sensor should be positioned, ideally, at the height of the required zero measurement. Based on this measuring point, the sensor will measure the hydrostatic pressure as a direct scale of the distance from the selected measuring point to the medium's surface.

The measured hydrostatic pressure of a liquid, in addition to the weight force of the medium, also includes the ambient pressure acting directly on the liquid's surface. The overlying pressure of the ambient air or gas pressure can be considered as a force which acts on the pressure sensor in addition to the liquid's weight

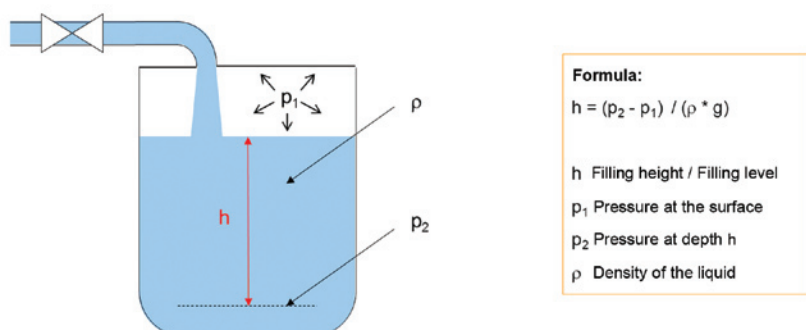


Figure 2: Level measurement in sealed, gas-tight tanks and vessels.

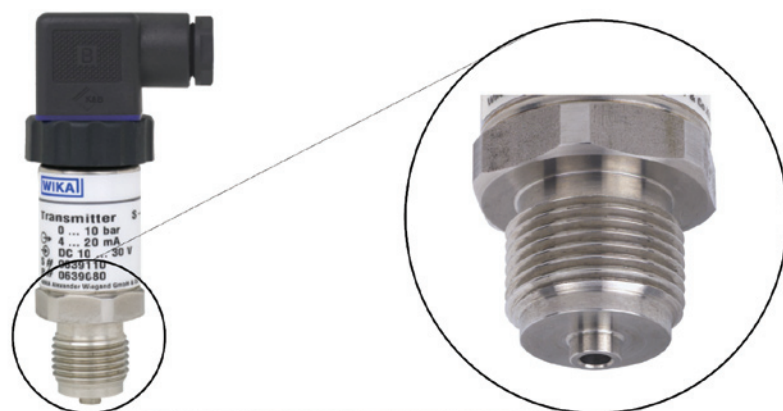


Figure 3: WIKA S-10 conventional pressure transmitter with pressure port.

force as a hydrostatic pressure.

## Level measurement in open, vented vessels

In open or vented basins or vessels, a continuous pressure compensation of the ambient air with the gas phase above the liquid takes place. Thus the ambient pressure that acts on the medium as an additional "force" always resembles the ambient pressure acting on the whole system, including the level sensor. If one therefore uses a relative pressure sensor that is compensated or vented (just like the tank) to the ambient pressure, it "automatically" compensates for the effect of this ambient pressure on the level measurement. A relative pressure sensor on a vented vessel completely "cancels out" the atmospheric pressure overlying on the liquid from the level measurement. Thus, the hydrostatic pressure corresponds only to the filling height of the liquid (Fig. 1).

Therefore, the filling height of an open tank or vessel is calculated using the following equation:

$$h = p / (\rho * g)$$

$p$  = hydrostatic pressure [bar (relative)]  
 $\rho$  = density of the liquid [kg/m<sup>3</sup>]  
 $g$  = gravitational force or gravitational acceleration [m/s<sup>2</sup>]  
 $h$  = height of the liquid column [m]

As a simple rule of thumb for water as a medium, one can assume that a pressure of 1 bar (relative) corresponds to a filling height of 10 m.

**Rule of thumb** (media of density  $\sim 1000 \text{ kg/m}^3$ ):  $h = 1 \text{ bar (relative)} / (1000 \text{ kg/m}^3 * \sim 10 \text{ m/s}^2) = 10 \text{ m}$

## Level measurement in sealed, gas-tight vessels

The level measurement in sealed, gas-tight vessels, which is frequently found in the chemical industry, requires a compensation for the pressure of the enclosed gas phase above the liquid. This compensation is done through an additional pressure measurement of the gas phase. This application effectively represents a differential pressure measurement, where the two separate pressure measurements are offset against each other (Fig. 2). This offset calculation can be made either by two individual sensors or via an integrated differential pressure sensor. When using two sensors, the sensors can be either relative (sensor with ambient pressure compensation) or absolute pressure variants (sensor with sealed vacuum reference).



Figure 4: WIKA UT-10 process pressure transmitter.

Thus, the filling height of a sealed tank or vessel is calculated using the following equation:

$$h = (p_2 - p_1) / (\rho * g)$$

$p_2$  = hydrostatic pressure [bar]  
 $p_1$  = pressure of the enclosed gas in the vessel [bar]  
 $\rho$  = density of the fluid [kg/m<sup>3</sup>]  
 $g$  = gravitational force or gravitational acceleration [m/s<sup>2</sup>]  
 $h$  = height of the liquid column [m]

## Types of hydrostatic level sensors

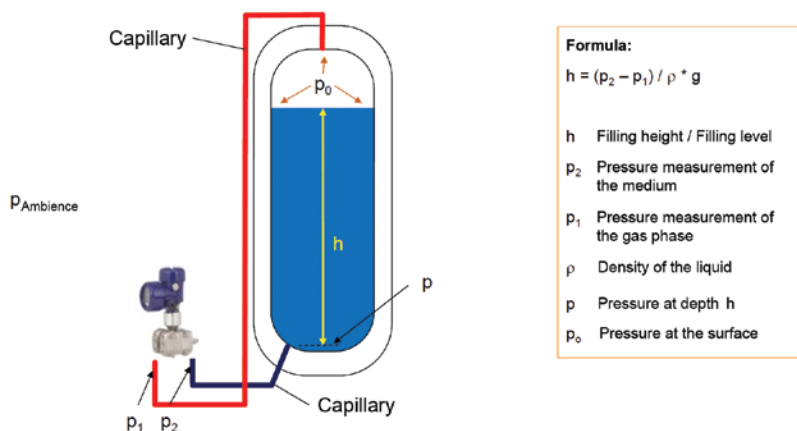
In hydrostatic level measurement, one can differentiate three types or designs of level sensors: conventional pressure transmitters, process pressure transmitters and submersible pressure transmitters, available in relative, absolute and differential pressure variants. For application in tanks and free-standing vessels, conventional pressure transmitters (Fig. 3) or process pressure transmitters



**Figure 5: WIKA S-11 conventional pressure transmitter with flush diaphragm.**

(Fig. 4) are particularly suitable. Conventional pressure transmitters are the most commonly employed, due to their excellent price/performance ratio. They are robust, simple to install and operate, fast, and available with a range of accuracies up to  $< 0.1\%$ .

Process pressure transmitters, however, are primarily used in applications with special demands on the measurement technology (such as bus signals, scalability of the measurement range, integrated tank linearization, etc.) and are mainly found in applications in the chemical and petrochemical industries. The extensive adjustability and high intelligence of these programmable process pressure transmitters is also reflected in their price level, typically five to ten times the cost of a conventional pressure sensor.



**Figure 6: Hydrostatic level measurement using differential pressure sensors.**

Conventional and process pressure transmitters can both be equipped with flush mounted diaphragms (Fig. 5) for use on fluids that have low viscosity, contain coarse grained particulates or can crystallize. The flush mounted diaphragm prevents plugging of the pressure transmitter's port to maintain accurate readings.

Specifically in the water and wastewater industry, submersible pressure transmitters ('level probes' or 'submersible probes') are frequently used to measure the level in reservoirs, wells or other open bodies of water (Fig. 8). Submersible pressure transmitters are specifically designed to operate while continuously submerged in liquids. They mainly differ from conventional pressure sensors in their media resistance, pressure tightness, cable quality and ingress protection.

The design of differential pressure transmitters (Fig. 9) is considered as state of the art technology within the chemical and petrochemical industry. Differential pressure transmitters offer the ability to measure and eliminate the effect of

the gas phase in a gas-tight sealed tank, and correctly display the level of the liquid phase within the tank. The operator therefore has a hydrostatic level measurement which displays the correct liquid height without the need of any additional compensation or additional sensors. The sophistication of this measurement technique is however reflected in the costs of both the instrument itself as well as the corresponding installation.

In the differential pressure measurement with process transmitters (Fig. 6) the mounting position is a common source of inaccuracy in the level measurement. The measuring points of the medium and the gas phase are typically connected to the differential measuring cell of the transmitter by oil-filled capillaries (indicated in blue and red respectively). The height difference of these measuring points to the differential pressure transmitter lead to an additional hydrostatic pressure within the capillaries (see Fig. 7) themselves.

This effect generates an additional over or under-pressure in the hydrostatic pressure measurement, ultimately distorting the measurement. The resulting inaccuracy can be corrected by a position correction factor and proper configuration of the differential pressure transmitter, so that an automatic correction can be done. It is also recommended that the transmitter be positioned below the height of the level measurement point in order to eliminate any negative hydrostatic pressure or under-pressure from the level measurement.

### Advantages and limitations of hydrostatic level measurement

Hydrostatic pressure and level measurement enjoys a consistently high popularity due to its high robustness, high reliability and simple installation of this technology. The following characteristics constitute the greatest advantages and limitations over other measuring principles:

#### Advantages:

- Proven and established measuring principle with high reliability, field-tested millions of times
- Robust measuring process, uninfluenced by disruptive factors such as dust, foam, vapour, build-up, contaminants, etc.
- Reliable measurement unaffected by many physical characteristics such as conductivity, dielectric coefficient or viscosity
- Level measurement unaffected by vessel geometry and existing installed equipment
- Simple installation and operation of submersible pressure transmitters and conventional pressure sensors without the need for calibration or adjustment
- Direct contact with the medium
- Numerous alternative design variations and sensor technologies for almost every application

#### Limitations:

- Unsuitable for bulk material
- Accurate measurement requires either media with constant density or continuous density measurement of the medium

#### Source:

1. VDC Research Group, Inc.: What's driving the process level measurement & inventory tank gauging markets, 2011

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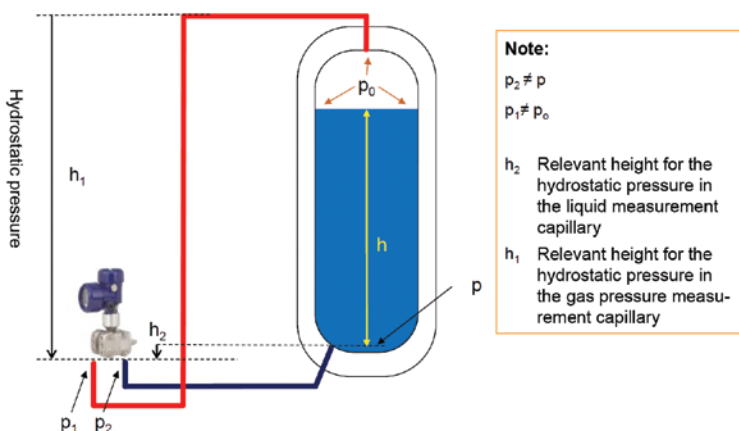
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**Figure 8: WIKA LH-20 submersible pressure transmitter.**



**Figure 9: WIKA DPT-10 differential pressure transmitter.**



**Figure 7: Effects of positioning on differential pressure sensors in level measurement.**