



Level



Pressure



Flow



Temperature



Liquid
Analysis



Registration



Systems
Components



Services



Solutions

White Paper

Liquid level measurement - Basics 101

Part 1

John Schnake

Executive Summary

The perfect level technology that works for every liquid level and point level application does not exist. Hydrostatic pressure has been around, it seems forever, and is proven in many applications. Non-contact radar and guided wave radar level instrumentation are popular and growing. Capacitance and conductivity have long histories of success in certain applications. However, it is still true that certain level technologies work better for some applications than other level technologies. This paper will explore a number of technologies for measuring liquid level and point level and will allow the reader to understand the basics of each technology with its inherent advantages and disadvantages.

This paper is available in its entirety, or in three separate parts. The first part of this paper focuses on hydrostatic level measurement. The second part focuses on continuous liquid level measurement utilizing newer technologies and the third, and last part, focuses on point liquid level measurement.

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Liquid level measurement - Basics 101 Part 1

Introduction

Level measurement is one of the “Big 4” measurements in industrial plants. As important as flow, pressure and temperature, the worldwide level market in 2004 was estimated at US\$1.32 Billion. Approximately 12% of all measurements in the industrial marketplace are used for level measurement. The market estimate included continuous level devices which measure the continuous level of liquid or solids in a tank, as well as point level devices which measure liquids or solids at one or more points in a tank. This paper will focus on those devices used for liquid level measurement. Continuous level devices are used when it is important to control or monitor the material at all points in a tank – 0% to 100%. Point level devices are usually used when it is important to know the lowest point or highest point. Why do continuous level devices and point level devices exist? Industrial plants must store raw materials and finished materials, process and mix many materials and buffer some materials for intermediate processing. Moreover, some plants want to know how much material they bought or possess in terms of volume or mass, some want to know how much they will be mixing and some want to know how much finished product they have or will sell.

Different types and shapes of tanks exist for these needs. They include storage tanks, buffer tanks and other process tanks. Tank shape as well as physical and electrical properties of the liquid, presence of foam and material agitation are some of the reasons why different types of level measurement device exist. One of the oldest and still the most common device for measuring liquid level is hydrostatic – a device that measures the pressure. Although hydrostatic has the highest market share in units and dollars, many predict its decline. And while the trend in the industrial market is towards non-contact measurement devices, including level, the decline may not be as fast as earlier predicted. While there are many arguments on the matter, one thing remains true: there is no perfect level technology that could or should be used in all liquid level applications. When purchasing liquid level devices, one should do some research

to understand the “Advantages” of each technology and the “Things to know” of each technology.

Hydrostatic devices for liquid level measurement

Pressure transmitters can be used to measure the pressure of steam, gases and liquids in industrial plants. However, they are more commonly used to measure flow rate of steam, gases or liquids, or the level of liquids in tanks. Robust and well-known, pressure transmitters (known as hydrostatic devices when measuring liquid level) are the most common measuring device for liquid level in a tank. The theory (see equation 1 below) can be explained as follows:

Equation 1 – Hydrostatic level equation

$$P_v = \rho x g x h$$

P = pressure exerted by a liquid column
 h = Height of the Liquid column
 ρ = density of the liquid
 g = gravitation constant

Equation 2 – Simplified level equation

$$h_v = P / s.g.$$

h = Height of the Liquid column in inches
 P = pressure exerted by a liquid column in inches of water
 s.g. = specific gravity of the liquid

In 1648, Blaise Pascal was the first to prove that the existence of a column of air above earth presses down and causes atmospheric pressure. The same theory applies for a column of liquid. Pressure is defined as the amount of force per area. A common unit for pressure is pounds of force per square inch or kilograms per square centimeter. Height or the level of a liquid can be measured in inches, mm, feet, meter, etc. Density is the mass of the liquid relative to the volume. When using hydrostatic to measure the level of liquid in a tank, the height of a liquid column (the level) is equal to the pressure exerted by that liquid column divided by the gravitation constant and density. To simplify the engineering units and resulting calculation of height or pressure, Equation 2 should be considered. You now only have to consider the specific gravity instead of the gravitational constant and density. Specific gravity is defined as the density of a liquid relative to the density of water. The specific gravity of water is 1. Consider a tank of 10 feet of water, whether in a tank that is 1 foot diameter or 40 foot diameter (diameter of the tank has no effect on the pressure). 10 feet = 120 inches. 1 psi = approximately 2.78 inches of H₂O at 39.2 degrees F. Therefore, 10 feet of water would exert 4.3 psi. Equation 2 can also be used for other liquids besides water since it uses specific gravity. A liquid with a level of 10 feet with a specific gravity of 1.2 would exert 20% more pressure than 10 feet of water. Why? Pressure = specific gravity x height. Therefore, this liquid with a specific gravity of 1.2 would exert 5.2 psi. Equation

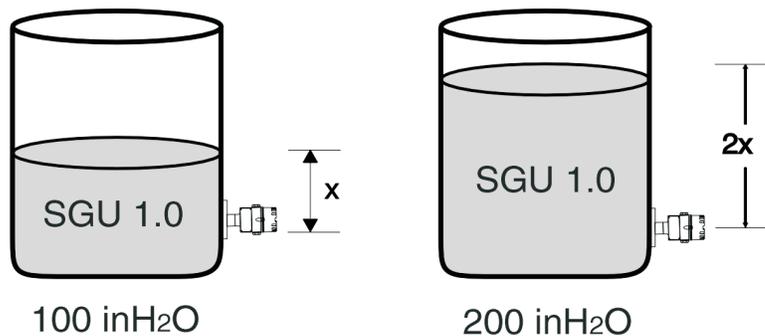


Diagram 1 – Level measurement in an open tank

2 can be used to calculate liquid level in an open tank (vented to atmosphere) or a closed tank (pressurized). See Diagram 1 for an example of open tank level measurement.

Normally, the pressure transmitter, more specifically a gauge pressure transmitter that is referenced to atmosphere, would be mounted at the zero point. In this example, a tank of water with a level of 200 inches will exert twice the pressure than a tank of water with level of 100 inches.

When liquid level measurement is needed in a closed (pressurized) tank, a gauge pressure will not work. The reason is that gauge pressure will measure the pressure exerted by the liquid as well as the vapor pressure above the liquid. We need a way of canceling the vapor pressure out of the measurement. A differential pressure transmitter must be used for this task. The differential pressure will measure a high side pressure and subtract the low side pressure. In this case, the DP transmitter will measure the pressure of the liquid plus vapor pressure above the liquid as the high side and the vapor pressure above the liquid as the low side. Therefore, the vapor pressure will be subtracted and the device will only measure the pressure exerted by the level of liquid. See Diagram 2.

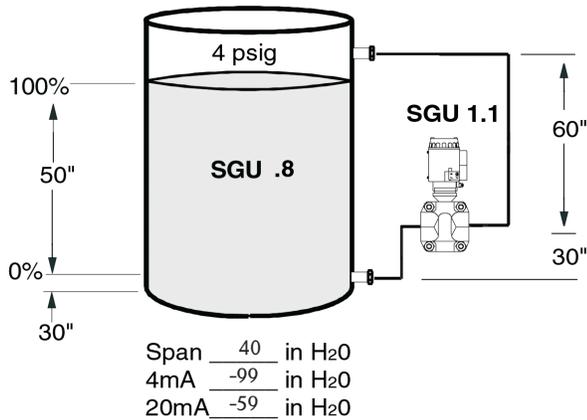


Diagram 2 – Level Measurement in a Closed Tank

Various process connections exist for the pressure transmitter when attaching to the tank. Pressure transmitters can be attached to a tank via ANSI or DIN Flanges (1"– 4") as well as threaded 1/2" NPT or 1" NPT connections. Care must be taken though when using DP transmitters to measure liquid level in a closed tank. If the vapor

pressure in the tank is not hot, a dry leg (just process media) can be used on the low side of the DP transmitter to measure it. If it is a hot process, like a boiler, the low side will need to be a wet leg (filled with water or something else) to insulate the pressure transmitter from the heat. Common transmitters can only handle about 250°F. In this case, a wet leg can be maintenance intensive. If one still prefers hydrostatic measurement in this case, there is a more costly but somewhat less maintenance intensive solution. Remote diaphragm seals are used when the process is too hot, the process media is viscous or contains solids, the process media can solidify, the maintenance group is tired of wet legs or one just wants to mount the pressure transmitter remotely from the process. See Diagram 3 for examples of remote diaphragm seal pressure transmitters.

Remote diaphragm seal pressure transmitters consist of a pressure transmitter, coupled to a remote diaphragm seal by capillaries filled with a fluid such as silicone. They can be used as gauge versions (single diaphragm seal) for open tank measurement or differential version (two diaphragm seals) for closed tanks. In either case, Equation 1 still applies for determining

the liquid level based on pressure. However, the remote diaphragm seal pressure transmitter is different in that the process pressure is exerted on the remote diaphragm membrane which exerts pressure on the fill fluid in the capillary which exerts pressure on the transmitter membrane which exerts pressure on the transmitter fill fluid which finally, exerts



Diagram 3 – Remote diaphragm seal pressure transmitters

pressure on the transmitter sensing device. This means that the remote diaphragm seal transmitter, while a good product for many applications, is a little more complicated than just using a pressure transmitter only for level measurement. There are a number of good software programs from pressure transmitter vendors that can be used to assure customers that the remote diaphragm seal pressure transmitter can be engineered properly for the intended level application. Just like the various process connections on a pressure transmitter, there are a number of type and sizes of diaphragm depending on the tank connection. See Diagram 4 which includes ANSI Flush Flange, Flush Flange with Extended Diaphragm, Pancake Seals, Off-line Threaded and Sanitary seals for the hygienic industries.



Diagram 4 – Remote diaphragm seal pressure transmitters

There are a number of reasons why hydrostatic devices are used for liquid level measurement. See Diagram 5 for Advantages and Things to know. Hydrostatic devices are well-known, reliable (proven in use), do not require field calibration, can be used for many liquids and are not effected by dielectric constant of the liquid or foam. However, there are also level applications in which one should be careful. One of the biggest

knocks on hydrostatic (see Equation 1) is that if the density of the fluid is changing, your measurement can be inaccurate. Another is that the hydrostatic is not as accurate as newer technologies like radar and ultrasonic. Remote diaphragm seal transmitters can also be costly and exhibit inaccuracies if there is a temperature differential between the low side and high side.

Advantages

- Low purchase price
- Well known, universal (level, pressure, and flow) and easily selectable
- Broad media compatibility
- Unaffected by foam, conductivity or dielectric constant
- No blocking distance
- Proven reliability

Things to know

- Measurement affected by density changes
- High maintenance
 - for wet legs
 - re-zero the instrument
- Temperatures and changing densities can affect measurement accuracy
- Remote seals can be costly for aggressive media applications
- Hygienic applications with cold media and hot CIP

Diagram 5 – Advantages & Things to know with hydrostatic level measurement

This paper is one of three parts. For the complete paper, please request CP024F/24/ae.

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