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Density and Concentration Continuous Measurement in Industrial Processes

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Many methods are available for density measurement in industrial processes based on different Technologies, such as: nuclear meters, refractometers, Coriolis effect mass meters, vibrating tuning-fork measurement, aerometers, laboratory analysis, etc. By using the principle of the hydrostatic pressure differential with an immersion probe and two integrated pressure sensors in a single unit, the capacitive density and concentration transmitter measures in a continuous and exact way the density and concentration of liquids.

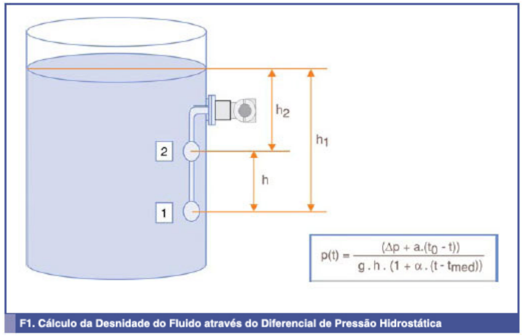
Several industrial processes require continuous density measurement to operate efficiently and ensure quality and uniformity to the end product. They include sugar and ethanol mills, beer plants, dairy makers, chemical and petrochemical, mining and pulp and paper industries. Density is the best indicators for a product composition and was used by Archimedes (250 b.C.) to determine that king Hiero´s crown was not made of pure gold.

The following items present the capacitive density transmitter features for that purpose.

The first theme presents the capacitive density and concentration digital transmitter, on item 1 its work principle, on item 2 its installation and mounting procedures, on item 3 calibration and startup details, on item 4 operation and maintenance specifics. The second theme compares the capacitive density transmitter with other existing technologies. The third theme lists the transmitter most frequent applications. And the last subject is the conclusion to this article.

Digital Density and Concentration Capacitive Transmitter

This device uses the principle of differential pressure measurement.



F1. Calculus of Fluid Density through the Hydrostatic Pressure Differential

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1. Work principle

The equipment uses a capacitive differential pressure sensor that communicates via capillaries with the diaphragms immersed in the process fluid separated by a fixed distance.

The differential pressure on the capacitive sensor will be directly proportional to the density of the measured liquid (see figure and formulas). This differential pressure value is not affected by the liquid level variation nor the vessel internal pressure.

In addition the capacitive density transmitter has a temperature sensor located between the pressure sensors to correct and normalize the calculations taking into account the process temperature. The process temperature corrects the distance between the diaphragms and the volumetric variation of the capillary fluid filling, which transmit the sensor pressure to the capacitive cell.

As the differential pressure sensor is a capacitive type, it generates a digital signal. And since the signal further processing is also digitally made, the result is high stability and exactness in the measurement.

With the information produced by the sensor and the process temperature, the electronic software calculates the density or concentration by emitting a current or digital signal proportional to the user-selected density or concentration (ºBrix, ºPlato, ºBaumé, g/cm3, etc.).

The same information can be accessed on the local digital indicator or remotely through digital communication.

The intelligent capacitive density transmitter offers the exactness of ± 0,0004 g/cm3 (± 0,1 ºBrix), and can be used on density measurement from 0,5 g/cm^3 to 5 g/cm3.

This measuring method is immune to vessel level variations and can be used both in open and pressurized tanks. The only mandatory rule is that both pressure sensors be in permanent contact with the fluid being measured.

Another important advantage is the transmitter robustness, since it does not have movable parts nor is affected by plant vibrations, unlike density meters based on the oscillation of a sensor element.

1 a. Density Measurement

The capacitive density transmitter measures the density of liquids as shown on figure 1.

The hydrostatic pressure applied on the capacitive density transmitter:

$P_1 = \rho . g . h1$
$P_2 = \rho . g . h2$
$P_1 - P_2 = \rho . g . (h1 - h2)$
$\Delta p = \rho . g . h$
$\rho = \Delta p / g . h$

Density calculation uses the formula shown on figure 1, where:

ρ: Density
t : Process Temperature
Δp : Pressure Differential
a: Filling fluid compensation coefficient
t_{zero} : Transmitter calibration temperature
g : Local gravity acceleration
h : Distance between diaphragms
a : Metal dilatation coefficient
t_{med}: Measurement of h temperature

1 b. Concentration measurement

Concentration is the quantity of an element in a solution and this measurement does not depend on the temperature, unlike density.

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If a solution has 25% of sugar at 20ºC, the solution will have density p; when the solution is heated at 60ºC, the sugar concentration on the solution will be the same 25%, but its density will be p', when p' < p, because whenever a liquid temperature increases, its density decreases.

So, some industrial processes use concentration as the measurement unit and for process control. The most used concentration units are:

Brix Degree and Plato Degree: they indicate the sucrose mass percentage in a solution. For example: In a 30°Brix solution there will be 30g of sucrose in 100g of solution. Utilization: sugar and ethanol industries, beverage, sodas, beer industries, etc.

Baumé Degree:there is two different formulas for Baumé degree calculation, one for liquids lighter than water and the other for heavier liquids: °Bé (light) = 140 / DR @ 60°F – 130; °Bé (heavy) = 145 – 145 / DR @ 60°F. Utilization: chemical, petrochemical, pulp and paper industries.

INPM Degree: it is the alcohol weight percentage in a hydro-alcoholic solution. For example: a hydro-alcoholic solution at 97ºINPM contains 97 g of alcohol in 100g of solution. Utilization: alcohol distilleries, etc.

GL Degree (Gay Lussac): it is the alcohol percentage volume in a hydro-alcoholic solution. For example: a hydro-alcoholic solution at 97ºGL contains 97 g of alcohol in 100g of solution. Utilization: alcohol distilleries, etc.

API Degree:it is calculated by the °API = 141,5 / DR @ 60°F – 131,5 expression. Utilization: petroleum industry.

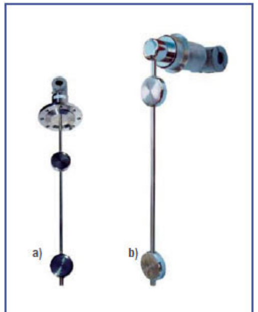
Solids %: the solids percentageof a fluid can be calculated by the following equation:% Sol.=a0 + a1.Bé + a2.Bé2 + a3.Bé3 + a4.Bé4 + a5.Bé5. A table relating the Baumé Degree fluid concentration to the solids % found in the laboratory presents the best equation connecting these variables. After configuring the a0, a1, a5, the capacitive density transmitter will inform the percentage of solids in the process fluid.

In the event of a process where more than one dissolved element varies its quantity, the solution density could be disproportional to the variation of concentration of one of these elements and the density transmitter will not be adequate to get its concentration.

2. Installation and mounting

As the capacitive density transmitter is a single and integrated unit, it is very easy to install and only requires being inserted in the recipient, a feature that differentiates it from other measurement systems.

This line of density transmitters includes an industrial model with flange mounting (figure 2 a) and a sanitary model connected to the process with a tri-clamp fitting (figure 2 b).



F2. Transmissores de Densidade Capacitivos

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In the sanitary model, the probe immersed in the process fluid has polished surface, according to the standard 3 A to avoid product deposits and the growth of bacteria. Both models can be mounted laterally in tanks or on top in sampling vessels. As the digital indicator can be rotated, the read-out will be comfortable in both mounting positions.

The capacitive density transmitter can be mounted with the on-going process, when installed in a by-pass through a sampling vessel. Due to its work principle, it does not require laboratory calibration and only has to be activated to start measuring immediately, as it is factory-calibrated and is user-calibrated at the chosen measurement range.

2a. Tank mounting

Generally, the curve type is the most adequate model for tank mounting. This model is mounted on the tank wall with a flanged or a tri-clamp fitting. When the transmitter cannot be installed directly in the tank, an external (stand-pipe type) sampling vessel can be used (see figure 3).

2b. In-line mounting

In processes that do not use recipients or storage tanks the measurement is possible with an in-line capacitive density transmitter. Just intercalate in the line a sampling vessel through which the process fluid will circulate, as shown on figures **4a and 4b**.

As the products gets in the sampling vessel simultaneously by the upper and lower parts, the measurement is not affected by the fluid circulating speed.

Another kind of mounting is using a sampling vessel with overflowing discharge, where the product gets in through the lower part and overflows on the upper part (figures 4c).

So the recipient is re-dimensioned so that the level of the constant liquid column that overflows covers entirely the transmitter pressure sensors.

3. Calibration and startup

The capacitive density transmitter is factory-calibrated at the engineering unit and the measurement range indicted by the user, and it is simply a matter of installing and activating the equipment to start working. In case of re-calibration or re-programming the work range, just connect to the transmitter a hand-held field programmer and begin operating, without interrupting the process. As the density and normalization calculations by temperature are carried out in the same unit, no further data are required than the density or concentration range that will be used.

This transmitter fundamental characteristic is that it does not need laboratory calibration.

The power is supplied by the same 4-20mA pair of communication wires, and the transmitter can generate a user-defined constant current output connection during the startup for checking.

Should the user need the density or the concentration value to be expressed on a unit other than the normally used (e.g., solids percentage), two options are available:

- A 5^{th}-degree polynomial with configurable coefficient to carry out the correlation between the user unit function and the density;
- A 16-point table with two inputs to carry out the linearization of the function that relates the user unit and the density.

By enabling one of these two options, the transmitter will primarily measure the density, while the local indication and digital output will follow the function loaded on the polynomial or on the table.

F3. Capacitive density transmitters

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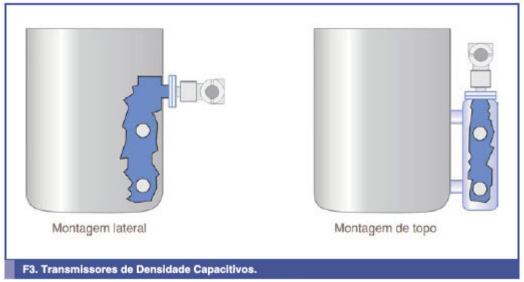

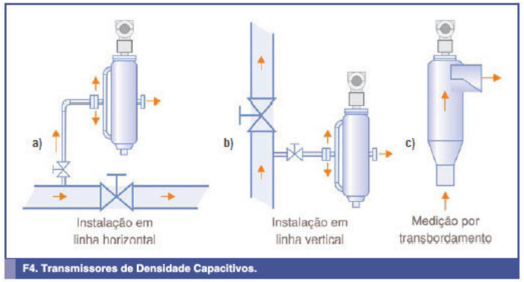

F4. Capacitive density transmitters

4. Operation and maintenance

The capacitive density transmitter provides direct indication in engineering units on the liquid density value, as well as its temperature, both in the local indicator and through digital communication.

This transmitter was designed to work with dirty fluid and suspension solids, without filtering. The pressure sensor project significantly reduces the product deposits and no frequent cleaning is necessary.

The sanitary model was designed especially for CIP cleaning systems, making sure that all transmitter parts in contact with the process be reached by the cleaning fluid.

1. The digital density and concentration capacitive transmitter compared to other technologies

1. Capacitive Density transmitter

The device provides exactness of ± 0.0004 g/cm³, allowing for the user to make a product with uniform quality, besides additives and energy savings. The capacitive density transmitter is a single and integrated unit, which requires only one tank perforation with no movable parts. In addition, the calculation for density and temperature compensation is performed in the electronic unit and does not need additional hardware, with the indications available on the field.

It can be installed in tanks or in line, with a sampling vessel. Since the transmitter has a probe in permanent contact with the process fluid, especial care must be observed when used with incrusting fluids. In this case, a cleaning system should be activated for the equipment probe.

2. Nuclear transmitter

The nuclear density transmitter uses a radioactive source, normally Cesium 137, to infer the fluid density. This equipment is made of two parts - a source and a receptor - installed at 180° in the process piping. The nuclear source emits gamma ray bundles

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that cross the pipe wall and the process fluid. The gamma rays are absorbed by the transmitter receptor. The fluid density is inversely proportional to the radiation received by the receptor. The radiation detected is converted to proportional light pulses, which are converted to electric 4-20mA signals or other usual process signals.

This method requires especial government permit to be installed, as it uses radioactive sources. In addition, it needs periodical inspection for possible radiation leak. The installation comprises the source, the detector, the electronic unit and the wiring. As the radiation source requires a power source, it cannot use a pair of cables.

This system can only be used in liquids in motion and cannot be installed in tanks.

The nuclear density transmitter does not have contact with the process fluid and is immune to corrosion, abrasion or incrustation.

3. Vibration tuning fork transmitter

This density measurement method uses a tuning or vibration fork, whose resonance depends on the density of the fluid it is immersed in. The tuning fork is stimulated by a piezoelectric exciter and the resonance is detected by a piezo collector.

Due to the high consumption involved, tuning fork transmitters require power source independent from the 4-20mA connection. This model is indicated for clean, non-corrosive, non-incrusting fluids, as it is in permanent contact with the process fluid.

4. Coriolis-effect mass transmitter

These devices are Coriolis-effect based for measurement of the fluid density as one of the parameters for mass flow calculation.

These meters normally use "U" shaped pairs of pipe, through which the process fluid circulates. The pipes are magnetically excited to provide a vibration frequency. When empty, they have a determined vibration frequency that is altered when a fluid is circulating through them. The relation between the pipes vibration frequency with and without fluid is proportional to the density.

The Coriolis type mass flow transmitters are installed in line in the piping and so are inadequate for tank measurement. They are indicated only for clean fluids without suspension solids, because they are narrow gauge pipes and can clog. Another impediment is about the interchangeability, as there is no standard regulating the dimensions between flanges.

5. Inferred density

This method uses a differential pressure transmitter with two remote seals or two pressure transmitters instead. Therefore the pressure can be measured in two points to infer the density. Normally an additional temperature measurement is required to calculate compensation. The installation needs the mounting of three transmitters in the case of some field computers that perform the calculation. Generally the density calculation is obtained in a central system and so is not available on field.

6. Refractomer

This density measuring method is based on light refraction. The transmitter is made of an optical prism, a light source and a sensor. The light source, normally infrared, sends a light bundle against the interface between a prism and the process fluid, with different angles. Some rays are totally reflected, others are partially reflected, while others suffer a refraction on the solution, depending on the angle.

The critical angle measured is a fluid density function. Photocells convert the optical image into electric signals. The refractometers are not 2-wire systems and require an outside power source, and the electronic unit is separated and interconnected to the sensor through a cable.

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The refractometer requires the prism that refracts the light to be always clean and especial care must be taken to prevent the accumulation of residues when installing it. This type of meter is applicable only to fluids in motion and are inadequate for direct installation in tanks.

7. Aerometers

Aerometers do not provide continuous measurement and are used on periodical measuring by collecting samples from the process fluid. Some applications require especial precautions, as the handlers can be exposed to toxic or corrosive substances when gathering them or manipulating them later.

The exactness of the measurement obtained is generally very low.

8. Laboratory analysis

Similarly to aerometer measurements, lab analysis must collect a process fluid sample and analyze it.

In spite of the good level of accuracy provided by this type of measurement, in many cases they not correspond to reality, as the ambient conditions cannot be reproduced in laboratory and analysis errors may occur.

In quickly changing process, as in fermentation, the delay in the results may induce to wrong decisions because the value obtained lacks validity.

Applications

The versatility of the capacitive density transmitter allows the use of the most indicated measuring unit according to the process. The transmitter indication is expressed in density units such as : g/cm3, kg/m3, lb/ft3, relative density (@20ºC, @4ºC) or concentration (ºBrix, ºBaumé, ºPlato, ºINPM, ºGL, % of solids, % of concentration).

The exchange of a measurement unit for another does not require recalibrating the transmitter.

Some frequent applications are:

Sugar and ethanol plants:

- Must and honey Brix degree;
- Evaporators syrup Brix degree;
- Distillation columns output INPM degree;
- Lime milk Baumé degree;
- Decanter mud density;
- Ethanol/cyclohexane interface level.

Food industries:

- Fruit concentrated juice;
- Dairy and condensed milk;
- Miscella concentration in vegetable oils;
- Starch dilution;
- Honeys, marmalades, etc.

Beverage industries:

- Beer fermentation Plato degree;
- Beer cookers Plato degree;
- Alcoholic degree (INPM or GL);
- Syrup dilution Brix degree;
- Dairy products density;
- Soluble coffee Brix degree.

Chemical and petrochemical industries:

- Acids density and concentration;
- Caustic soda density;
- Sodium chloride density;

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- Lime Milk density;
- Gas, kerosene, diesel oil, GLP densities;
- Water/oil interface level.

Pulp and paper industries:

- Potassium hydroxide concentration;
- Liqueur concentration (black liqueur, green liqueur, etc.);
- Lime mud density;
- Caustic soda concentration;
- Starch dilution;
- Cellulose dilution.

Mining:

- Orepulp density;
- Thickener pulp density output ;
- Flotation cell input and output density;
- Concentration spirals output density;
- Mud extraction density;
- Acids dilution;
- Lime mud density.

Conclusion

The use of a density transmitter for continuous density and concentration in industrial processes provides many benefits, like process automation by decreasing its variability, process optimization by reducing the use of reagents and energy, drastic elimination or reduction of manpower related to sample gathering and laboratory analysis, elimination of losses and wrong read-outs related to sampling, provision of real-time data for process management and control, maximum availability of data for process statistical control and quality control improvement, increase of process reliability to ensure better uniformity and quality in the end product.

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