What Criteria to Consider in Selecting a Water Cut Monitor known as Basic Sediment and Water Meter (BS&W)

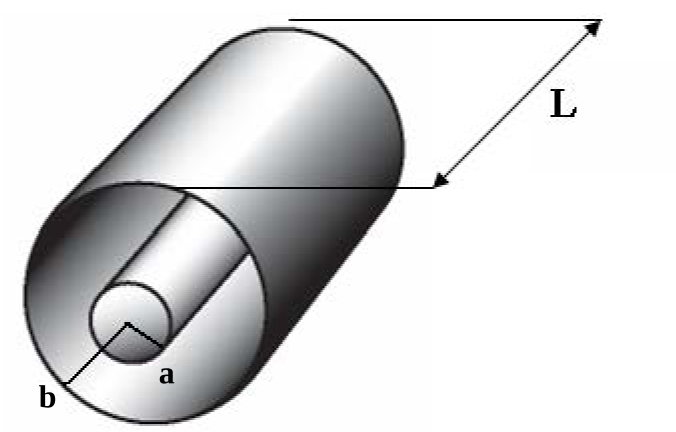
Water Cut Monitor Technologies and Factors that Affect Their Performance

Measuring the percentage of water in oil (water cut) is required for both upstream and downstream oil production. Several technologies currently are used to measure water cut across a full range of applications. Among the criteria for selecting which technology to use includes accuracy, sensing range, process characteristics, mechanical configuration, maintenance requirements and price. Each technology addresses the identified criteria through various design approaches. However, to achieve the greatest value and performance, device users should be conscious of their application parameters before selecting the right technology. This paper provides a basis for comparing the capabilities of water cut technologies, including their advantages and disadvantages.

Technologies

Four basic on-line analytical instrument technologies are used to measure the percentage of water in oil: Capacitance, Microwave, Spectroscopy, and Density. All of the four technologies rely on electrical and/or mechanical characteristics of the fluid in determining the measurement. Because of the differences in each of these sensing methodologies, device users should have at least a basic understanding of the strengths and weaknesses of each technology to select the right instrument for their application.

Capacitance: The oil industry has used capacitance technology successfully to measure water cut for over 40 years. That success is due to the significant difference in dielectric constants between oil (k≈2.3) and water (k≈80). **Figure 1** shows the sensing element, with diameter 'a', and the pipe wall, diameter 'b', that form the two plates of the cylindrical capacitor.



$$C = \frac{2\pi\varepsilon_0 L}{\ln(\frac{b}{a})}$$

Figure 1: Standard Cylindrical Capacitor

The system's electronics transmit a radio frequency voltage to the sensing element that measures changes in capacitance. As the amount of water in the flowing oil increases, the net dielectric of the fluid increases causing the capacitance to increase. The instrument's onboard electronics then computes the relationship between capacitance change and water cut.

Key advantages of capacitive instruments are stable (and proven) measurement technology, simple design, insensitivity to water conductivity, and an ability to handle a majority of oil patch applications. It is a common misconception that the capacitive instruments are limited to the linear segment of the capacitance vs. water-cut response curve. The capacitance instruments are able to extend into the non-linear range through the use of strapping tables. Typical capacitance instruments are able to put in multiple calibration points that can be fitted to the non-linear region of the curve. **Figure 2** shows the data points from a typical strapping table that tracks the changing water cut through a non-linear capacitance response.

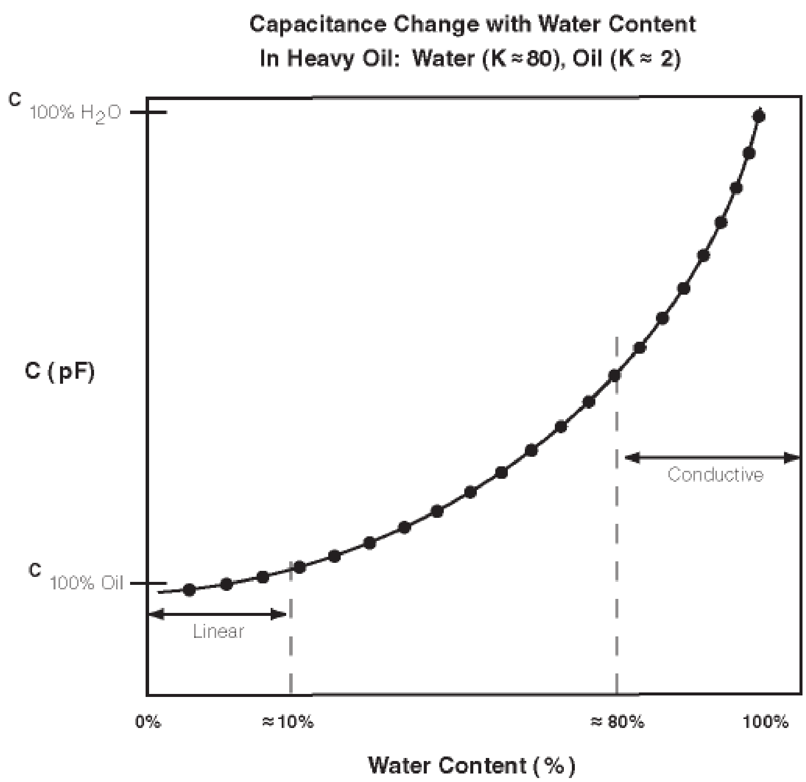


Figure 2: Correlation of Capacitance to Water Content

In addition, capacitive instruments are typically among the lowest cost options relative to other measurement technologies.

Disadvantages of capacitive instruments are their difficulty in handling changing process factors (see below) and their limitations in measurement range. Capacitive instruments are limited to water cut ranges that are below the inversion point of oil and water. As the fluid becomes water continuous (see Figure 2 above), conductivity dramatically increases, creating an electrical short to ground. The short to ground drives the capacitance to infinity and obscures the dielectric information. This phenomenon typically occurs at approximately 50% water cut in light oil and at 80% in heavy oil.

Microwave: This technology relies on the different electrical properties of the oil/water mixture to determine the water cut measurement. An oscillator transmits a microwave signal at a precise frequency via an insertion probe that travels through the fluid. As the percentage of water in oil rises, the microwave signal changes in amplitude and frequency. That change in signal is measured electronically and the relationship between microwave signal change and water cut determined.

Advancements in microwave technology have provided this methodology with several distinct advantages. Two of these are an accuracy in the lower cut ranges and the capability to measure the full range of water cut (0-100%). The microwave-based systems also are more robust in handling process factors that can negatively affect other water cut measurement technologies. Disadvantages of microwave technology include its high initial cost relative to other technologies and sensitivity to salinity changes in the higher cut ranges. Further explanation of the effects of salinity on water cut is outlined below.

Spectroscopy: The basic principle behind spectroscopic measurement of water cut is the response of an oil/water mixture to light. A spectroscopic device emits an infrared beam that ignores the water phase of the mixture. The sole reactant to the selected wavelength is the oil phase. Signal receptors on the device, shown in Figure 3, measure the absorption, reflection, and scatter of the infrared beam and makes a direct correlation to water cut.

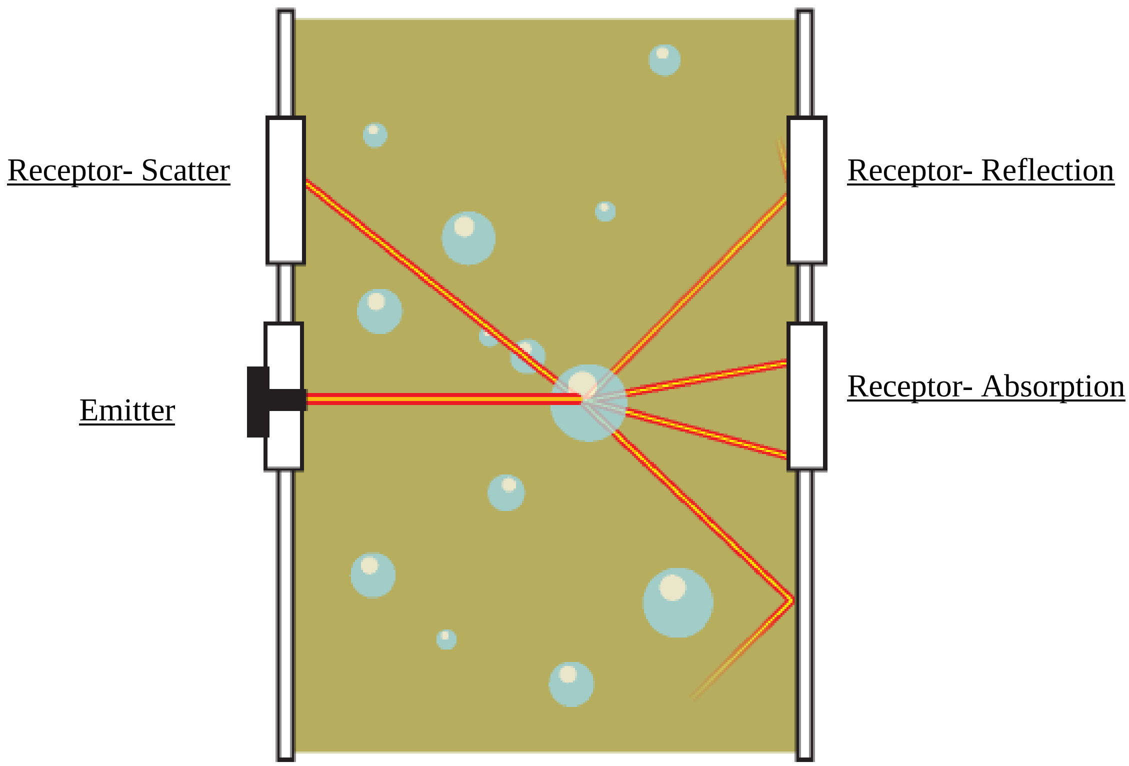


Figure 3: Signal Receptors for Spectroscopic Water Cut Device

Spectroscopy offers several advantages for the water cut measurement. First is its ability to measure across the full range of water cut. The percentage error actually decreases as the water cut increases. The technology's accuracy at the high end of the cut ranges separates it from other competitive technologies. Another advantage is the technology is unaffected by changes in density, salinity or entrained gas.

A major disadvantage of spectroscopy water cut products is they lack the necessary accuracy at the lower cut ranges. That lack of accuracy at the lower cut ranges limits the number of suitable applications. For example, spectroscopy-based measurements are not a good choice for Lease and Automatic Custody Transfer (L.A.C.T.) sites that have cut ranges of 0-3% water in oil per API Specification 11N. Users of infrared devices must also recognize that these instruments have a very defined sampling region. The sampling region emits an infrared beam that is reflected, absorbed, and scattered over a potentially small representative region of a very large sample. This narrow beam may, or may not, provide a true measurement of the entire process flow.

Density: Density measurement is the only methodology that uses a mechanical solution to measure water cut, and it is usually done with a coriolis flowmeter. To perform density measurement, fluid enters the flow tubes that are mechanically driven to vibrate at a certain frequency. **Figure 4** provides a typical arrangement for a coriolis flow meter. As the fluid's density changes, the frequency at which the tubes oscillate changes. The water cut can be determined from those changes. By knowing the initial densities of the water and oil, the output of the coriolis meter reflects the densities of the combined fluids. The coriolis meter electronically takes that output density and solves for the assumed single variable--water cut.

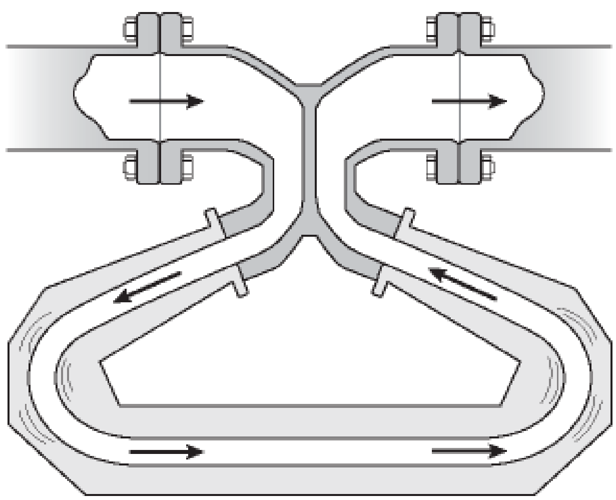


Figure 4: Coriolis Flowmeter

Density measurement does provide users with the ability to measure the full range of measurement. The technology is cost effective and provides additional information (flow rate, temperature, and density) that can be used as input for process optimization. A drawback to using a density measurement for water cut occurs when process variables start to change. Introduction of gas and salinity into the process immediately effects the water cut measurement and can significantly impact the accuracy of the device. The use of density to measure water cut is typically confined to light oils due to the limited difference in density between water and heavy oil. Density based water cut measurements encounter additional uncertainties when applied to water-flood enhanced oil recovery processes. The reservoir mixing of native and injected water creates uncertainty of the exact produced water density and thus uncertainty in water cut.

<u>Process Characteristics</u>

As outlined above, each of the measurement technology has its own strengths and weaknesses, depending upon process conditions. It is very important for users to identify process characteristics before deciding upon any particular technology. Below are key factors that have the greatest effect on which technology to use in making the water cut measurement.

Density: Any variation in density (degree API) significantly affects the capacitive, microwave, and coriolis/density measurement. As explained above, capacitive and microwave measurements are based on the electrical properties of the mixture. Therefore, any change to the electrical property, in this case the dielectric of the oil being shifted by density, severely impacts the measurement technique.

The introduction of entrained gas also affects the fluid's electrical properties of the fluid. Entrained gas will cause additional shifts in the net dielectric of a fluid that now has a mixture of entrained gas (k=1), oil (k=2) and water (k=80). Entrained gas causes a downward shift of the water cut measurement. The coriolis/density measurement also is affected by changes in API gravity of the fluid. Any change in API density requires re-calibration of the initial values entered into the sensor.

The oil industry has recognized the effects of varying densities and has made significant efforts to address these concerns in measuring water cut. Coriolis meters, to measure density only, are used in conjunction with microwave and capacitance probes to arrive at a corrected output. Separation techniques can also be used to reduce the amount of entrained gas within the process that can have a positive impact on the water cut measurement. In addition, several manufacturers have published specifications regarding sensitivity to density changes. Users should understand how density varies in their processes and choose the right technology to handle those variations.

Salinity: An increase in salinity and the subsequent increase in conductivity of the fluid have significant effects on the water cut measurement. Obviously, any instrument that depends on conductivity for water cut will be sensitive to changes in conductivity of the water. Any device that emits a transmission signal is dependant on the properties of the fluid to carry the signal as well. Changes in salinity will cause changes in the conductivity and ultimately changes in the electrical signal propagation through the fluid.

The effects of salinity have the greatest impact at the higher cut ranges, where the process becomes water continuous. In the oil continuous phase, the fluid is insulating and the floating salts have limited effect on the net conductivity. Once the fluid enters the water continuous phase, it becomes highly conductive and the salt content amplifies the electrical path to ground.

The four principal technologies for measuring water cut have varied responses to changes [in conductivity]. Antenna loading is affected the most because the measurement is based on the conductivity of the fluid. Density measurement also is affected by the introduction of additional solids in the measurement as described in the previous paragraph. Errors are associated with salinity in microwave-based devices only in the water continuous phase where the fluid is conductive. Microwave devices are calibrated for a specific conductivity and change in this property will result in a calibration error.

Manufacturers of capacitive technologies design their coaxial sensing element to reach full signal saturation and ignore changes in conductivity. The advantage of a saturated probe is that the signal detects changes in water cut only as long as the probe remains saturated. The disadvantage is that if the conductivity change is significant enough for the probe to lose saturation, then the electronics will not display the correct value. The majority of oil patch applications do not see enough salinity variation between well formations to lose probe saturation. However, with applications that may see oil from multiple sources (such as the receiving point at a refinery) there is increased probability of losing probe saturation.

Temperature: Density, and, therefore, the dielectric constant of the fluid are affected by changes in the temperature of the process. As the temperature increases, the density decreases (reducing the dielectric) causing an error in the water cut measurement. Temperature variations do not cause as dramatic a response as changes in salinity or API gravity. However, the ability to correct for temperature fluctuations increases the accuracy and repeatability of the water cut measurement. That ability is particularly important in custody transfer applications, where a 0.5% change in water cut can have significant implications. Most manufacturers do some form of temperature compensation to correct for this effect.

Homogeneous Sample: The sensing element must be exposed to a representative sample of the fluid in order to make an accurate measurement. A common problem seen in process conditions is independent slugs of oil, gas, or water reaching the sensing element. These slugs are usually caused by some form of separation that occurs before it passes through the sensing area of the instrument. The separation is often more critical at water-cuts above 50% where the fluid property differences (density, viscosity, etc…) will cause a portion of the oil/water emulsion to separate into a free water phase. As this occurs, the measurement instrument is subjected to multiple parallel, and very different, fluids. **Figure 5** reveals the dynamic emulsion states that occur within flowing process conditions. Water cut devices are based on the assumption of a single phase measurement and now must attempt to understand a multiphase process consisting of free water and oil emulsion. Elimination of free water via additional process separators and the addition of inline mixers are some of the more common solutions to provide a true representative sample to the sensing element.

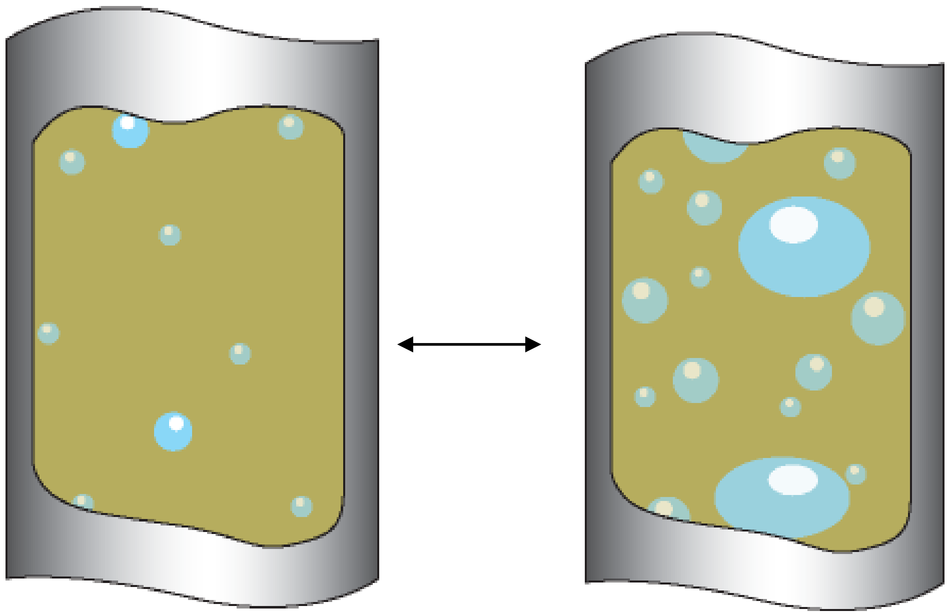


Figure 5: Dynamic Emulsion States

Individual Product Capabilities

If choosing the right cut monitor technology weren't difficult enough, there are more than 15 manufacturers of water cut instruments. All utilize the four basic technologies listed above. With that in mind, it's valuable to users to identify additional instrument characteristics that are of value to users.

Range of Accuracy: Some technologies are limited to certain cut ranges. Spectroscopy-based instruments are able to measure the whole range and increase in accuracy at the higher cut ranges. That technology, however, is not useful for accurate, low-range cut measurement. On the other side of the spectrum, capacitance devices offer excellent accuracy and repeatability at the low-cut ranges but are limited by the water/oil inversion point. Microwave measurements offer accuracy throughout the entire range, and their premium price reflects that capability.

With the technology limitations on accuracy at different water cut levels, it is clear why certain technologies are better suited for certain applications. The spectroscopy measurements are ideal for monitoring well testing at high water cuts and for discharged sump water. Conversely, applications at lower cut ranges are better suited for capacitance and microwave devices. Examples of applications that require lower cut range devices include custody transfer and pipeline monitoring. The user must decide the technology that best fits the measurement requirement as well as the instrument that best implements that technology.

Communication Output: While all instruments provide the standard 4-20 mA output, some manufacturers have equipped their devices with additional capabilities. Utilizing digital protocols, embedded relays, multiple 4-20 mA signals and wireless communications are just some of the output options being provided.

By incorporating these additional communication techniques, the instrument's electronics can transmit density, temperature, and net oil calculations. The additional outputs also reduce the need for extra sensors, thereby minimizing capital expenditures and maintenance expenses.

Embedded relays are of particular importance in applications where the cut monitors are used to divert oil with high-water content. The use of digital protocols is gaining in popularity because it allows users to remotely query the device for diagnostics or to make needed calibration changes.

Sensor Design: Various mounting options are available. Among the most common is the dual flanged spool piece. **Figure 6** provides a typical arrangement for spool-piece type cut monitors. A different approach taken by some producers are threaded NPT and slipstream designs that permits for a more customizable solution than a spool piece.

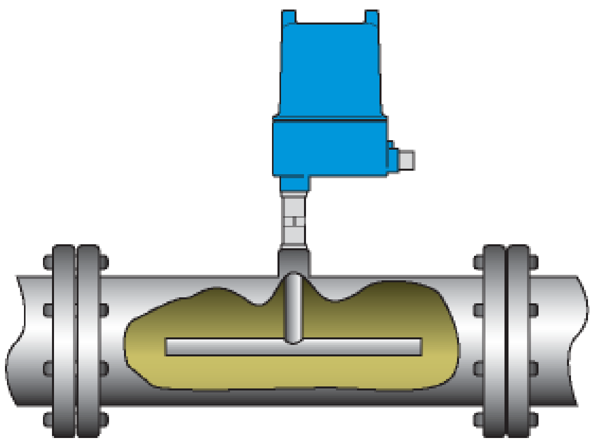


Figure 6: Spool-Piece Cut Monitor

Maintenance should be considered in choosing the correct sensor design. Users should ask if the probe is susceptible to paraffin buildup. How easy is the device to clean and/or replace? Does the sensing device measure a representative sample of the fluid? Are there any seals, coatings, or fittings that require regular replacement? How well the external electronics stand up to harsh ambient conditions? These questions all need to be addressed in choosing a particular design.

An insertion probe that can be installed directly in the process stream offers additional advantages when evaluating different sensor designs. For example, the insertion probe used by some capacitance devices allows the sensor to acquire samples over the entire length of the probe, providing a larger representative sample of the mixture. The longer probe creates a capacitive-averaging effect along the probe that allows the electronics to calculate a more accurate measurement. **Figure 7** shows a typical example of a cut monitor probe that inserts directly into the elbow of a pipe.

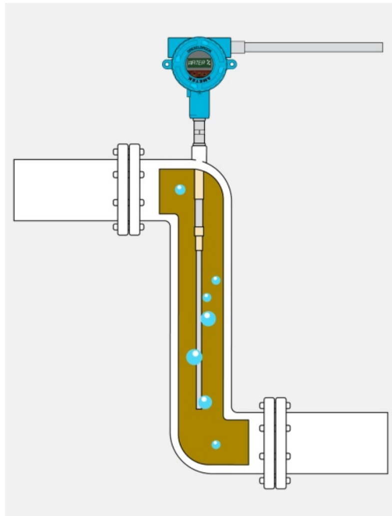


Figure 7: Pipe Insertion Cut Monitor

Net Oil Calculation: Net oil calculations are gaining in popularity with the integration of computing devices, PLCs, flow meters, and water cut instrumentation. A packaged net oil calculation offers end users a dedicated system that has been installed, calibrated, and optimized by a single supplier. It eliminates the need for users to piece together individual components to compute net oil calculations.

Start Up and Commissioning: A certain depth of knowledge and experience is required during installation of a new cut monitor to get the best performance from a unit. The level of service and local support an OEM provides is of great importance in choosing a device. Due to the increasing complexity of the various technologies, the use of factory representatives for installation and start up services has become a popular option with the purchase of these devices.

Price: Price varies significantly among cut monitor products. Users may end up spending anywhere from $2,500 to $30,000 for a device. Price is dependant on the range and capabilities of a device. Such extras as digital communications and net oil calculations may add significantly to the base price of the unit.

Conclusion

To get the best performance and value from a cut monitor system, it is necessary for the user to have comprehensive data on the process parameters and product characteristics that influence performance. New cut monitor systems should be evaluated on the basis of accuracy, sensing range, process characteristics, mechanical configuration, maintenance requirements, and price prior to making a purchasing decision. Armed with sufficient knowledge of the process and technology, such as the advantages and disadvantages outlined in this article, users will be better able to decide which manufacturer's instrument best implements the technology.

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