Evaluating Electrodeless Flow-through Conductivity Sensors for Sanitary Applications

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Introduction

Electrodeless conductivity sensing is often specified for sanitary aqueous applications because of versatility, range, and functionality combined with ease of installation, calibration, and maintenance. Of the two types of electrodeless sensors, invasive and non-invasive, invasive sensors are most ubiquitous and therefore often inappropriately specified for sanitary applications. The advantages of the noninvasive sensors come primarily from two aspects, the sensor presents no profile to the process liquid as the sensor is part of the process line, and as such, fluids flow right through and are complimented by a unique calibration capability.

This paper evaluates invasive and non-invasive conductivity sensors according to their suitability for typical sanitary applications. It compares them according to their purpose of measurement, certification requirements, materials of construction, installation, calibration, maintenance, and longevity attributes.

Purpose of Measurement

Monitoring physical characteristics of ingredients in sanitary processes is one of the main purposes for measuring conductivity in the lines. This might be done to maintain consistency of Food & Beverages such as yogurt or cheese, juice, milk, bottled water, and beer prior to bottling or packaging, or to monitor adherence to rigid quality control standards required for the production of demanding sanitary products (such as blood plasma or proprietary pharmaceutical solutions).

For such purposes, invasive and non-invasive sensors differ in their ability to measure lower conductivity levels. While both types of technologies can measure conductivity up to 2000 millisiemens/cm (mS/cm), invasive sensors typically offer a low-end capability of a few hundred microsiemen/cm (uS/cm), while flow-through sensors can measure conductivity at approximately 10 uS/cm. and above.

The conductivity range of most sanitary applications is between 50 uS/cm and 1 million uS/cm (1000 mS/cm), non-invasive sanitary sensors cover the broadest range of sanitary applications, suitable for the vast majority of sanitary applications. As illustrated by Table 1, most commonly produced Food and Pharmaceutical products have conductivity < ~ 10 mS/cm, while CIP solutions can range to several hundred thousand uS/cm, or more.

Within the respective conductivity range, temperature and pressure ranges are comparable with both technologies. Both provide accurate measurement at temperatures up to 284 degrees F, and pressure requirements for most sanitary applications ranging < 150 psi. The flow-through sensors, as well as the invasive sensors handle pressures up to 225 psi.

Therefore, from the standpoint of most sanitary applications, temperature and pressure capabilities are acceptable for either type of sensor.

A very common purpose for measuring conductivity in sanitary applications is to provide data for the control of clean in place (CIP) operations. Suitability of invasive sensors for this purpose varies, and depends on sensor material compatibility and flow profile, but non-invasive flow-through sensors are suitable for virtually all control applications. Flow-through sanitary sensors becomes a section of the process line, with a single wetted material exposed to the process.

Table 1

Conductivity ranges of commonly produced Food and Pharmaceutical products

Tap Water	~ 250 to 450 uS/cm
Beverages	< 5 mS/cm
Yogurt	< 2.5 uS/cm
Cheese	< 2.5 mS/cm
Pharmaceuticals	From ~10 uS/cm to many mS/cm
Medical Film (emulsions)	< 20 mS/cm

Sanitary Certification

Once the purpose is defined, it will be more apparent whether the application requires a truly sanitary rated sensor, such as that which meets 3A requirements. Processes involving ingestible substances such as milk and cheese might have sanitary requirements for all operations, from consistency monitoring to clean in place, while other applications may only require certification for one-step such as CIP chemical monitoring.

Some invasive sensors note 3A approved materials, though this does not necessarily mean that they provide a sanitary 3A design. Non-invasive sensors meet 3A requirements for both the virgin PEEK material, which compose the only wetted sensor section, and for the overall sensor design. In addition, flow-through sanitary sensors are available with non-invasive virgin PEEK bore piece material that is lot traceable for FDA compliance.

Invasive sensor design challenges that relate to certification include the materials used in the body, mounting connections, wetted o-rings, and other material/components, depending on their exposure to process liquids at various production stages.

Materials and Certifications

Process solutions and operating conditions are typically the next aspect to review. Maximum process temperature and pressure, combined with the nature of the process solution will help define the overall materials compatibility. It is advantageous for many sanitary applications to limit the number and type of materials exposed to the process solution. A virgin material that provides a wide materials compatibility and has achieved 3A approval and FDA compliance is preferable.

Figure 1 – Foxboro 871FT sanitary flow-through sensor composed of virgin PEEK

Invasive sensors typically provide combinations of stainless steel with Teflon, polyvinylidenedifluoride (PVDF), polypropylene (PP), or virgin polyetheretherketone (PEEK) materials. Increasing the number of materials exposed to the process solution increases the possibility of contamination, and ultimately sensor failure from leakage at the interface points. Multiple wetted materials can also complicate and add cost to maintenance. The only single-material, non-invasive sanitary sensor on the market today, from Foxboro®, provides a single wetted material, a bore piece entirely of virgin PEEK, the preferred material for sanitary applications. (See Figure 1.)

Conventional sensors are typically composed of a combination of materials as stated above. These tend to be lower in cost, but subject to more process issues. Newer sensors tend to be made primarily from virgin PEEK, a thermo-plastic material proven to be compatible with the widest array of process solutions. Standard industrial sensors might be composed entirely of glass-filled PEEK, while sensors designed for non-standard applications might include PEEK and alternate materials such as PVDF, PCTFE (polychlorotrifluoroethylene), Noryl, borosilicate glass, glass-filled Teflon, virgin polypropylene, and virgin PFA, and other thermoplastic materials.

In theory, any part of the sensor (such as electrode body, mounting connections, or o-rings), could be composed of any of the above, or other materials. In practice, very often the nature of the solutions involved in the sanitary process drives the choice of wetted material to a single thermo-plastic material, such as virgin PEEK. Instruments composed of suitable thermo-plastic elastomers can be designed for compatibility with more than 95 percent of all commonly used process substances.

Often, the more stringent the certification requirement, the less variation you want in the number of exposed materials, since each material and component should then be considered and approved, as well as their interface points and affect on design.

The finish of the sensor-wetted surface is another area that can vary with specification. With invasive sensors, the finishes vary widely across the profile shown to the flow. For non-invasive sanitary flowthrough sensors, the interior bore finish, the only point of the sensor that actually comes in contact with the fluid, is better than 16 micro-inches.

Installation

Most invasive sensors mount with integral (such as tri-clamp) connections, though at least one is available with a demountable tri-clamp connection and can be removed for cleaning.

The size of the process line is a very significant installation issue. Invasive sensors, as the name implies, actually protrude into the process line. They require a minimum three-inch ID mounting to operate effectively, so if, for example, the process line was only 1.5 inches, the line would have to be expanded to accommodate the invasive sensor. This could potentially impact process flow or product quality and would have to be examined thoroughly in context of the other requirements, including the potential of introducing a profile into the process flow. A profile to the flow can be a significant consideration for some Food & Pharmaceutical applications.

Process line size is often less of an issue for a process still in design phase where the sensor characteristics would be specified first and the process line size would be specified accordingly. A noninvasive sensor can simplify this, by being selected to match the preferred process line size.

Maintenance

Although sensor coating itself is not usually a measurement issue for either invasive or non-invasive sensors, the sensor body of an invasive sensor does introduce a "profile" to the process flow and may require cleaning, maintenance, and thus re-calibration of the sensor-electronics loop. In addition, if the bore hole of an invasive sensor were to become blocked, that would affect the measurement.

Flow-through sanitary sensors require the least maintenance because neither the sensing element nor the housing presents a profile to the flow. As such, flow-through conductivity sensors are much more effective for a wider range of sanitary applications, in such fields as Food & Beverage, Pharmaceutical, Biological, and Medical.

Calibration

Regardless of the approach selected, the conductivity sensing loop, - sensor, and analyzer - will require periodic calibration. To accomplish this re-calibration, the invasive sensor must be removed from the process line, cleaned and dried, then calibrated based on tables that correlate sensor parameters (cell factor) with resistance, or by taking readings from wet solutions themselves, an approach which is often fraught with inherent error. Once calibrated, the sensor must be re-installed into the process line and the line may then need to be re-certified.

Because of the need to remove invasive sensors due to coating issues, in some applications, invasive sensors may have to be calibrated more often. This is usually done with a decade resistance box, which can cost upwards of $1,000, and are at best cumbersome to transport from installation point to point.

Non-invasive sensors offer very significant advantages as they can be calibrated with a simple shirt pocket tool (usually in less than 10 minutes), utilizing a patented calibration tool that is inserted into the calibration port of the sensor. Accurate calibration of the sanitary flow-through sensor can take place, with the sensor in place, without stopping or interrupting the process flow with this precision resistance calibration tool.

To simplify this process, Foxboro has developed precision resistor calibration plugs that permit calibration of an electrodeless conductivity loop with a minimum of effort. (See Figure 2.)

In addition, since they are manufactured to the end users specific sensor series and desired conductivity value, they eliminate the need for plant personnel to determine sensor cell factors or compute relevant resistance values. Instead, they may be assigned as a 'tool' number to a particular installation point.

Figure 2 – Foxboro flow-through sensor with calibration plug

Cost

Although the purchase price of the invasive sensors can be lower, the cost of maintenance, possible retrofitting, downtime, and application suitability make the overall cost of ownership much higher. The purchase price of invasive sensors varies depending on the application requirements. For common applications, they are in the $1200 range. While sanitary Flow-through sensors are higher priced initially, they offer the most common line sizes (½", ¾", 1.0", 1½", 2.0", 3.0" or 4.0") and typically have an ROI of several months, or less.

Example – Conductivity Sensing Profile 1: Hypothetical Yogurt Manufacturer

For the following reasons, the Foxboro 871FT Sanitary Flow-through sensor was selected for this application:

- Virgin PEEK composition met both 3A sanitary certification and FDA compliancy certifications, and is compatible with all binary solutions encountered
- Wide selection of bore sizes (½", ¾", 1.0", 1½", 2.0", 3.0" or 4.0") meant that it could be matched to the 3-inch line size, without the need to replace the existing line
- Better than 16 micro-inch interior bore finish that would withstand the high volume, high frequency food process production flow
- Maximum temperature rating could easily with stand the < 212 F (100C) process conditions
- Tri-clamp connection met 3A sanitary requirements
- Non-invasive strategy presented zero profile to the flow/product, and required minimal maintenance, critical for food processors
- Conductivity range capability from ~10 microsiemen/cm to 2000 millisiemen/cm, easily accommodated the necessary range to accommodate the product, CIP solution (NaOH), and rinse water used in the application
- Calibrated in less than ten minutes, without stopping the process flow or opening the process line, and with only a shirt pocket tool added significant additional benefit
- The multiple application and Auto Switching feature of the electronics provided a key capability for the process control required

A hypothetical manufacturer of Yogurt monitoring NaCl content, 'fruit' content, and CIP

Product	Fruit yogurt
CIP	NaOH 2 - 5 % by weight
Rinse	Water 1000 to ~ 50 microsiemen/cm
Certification	3A material and design with FDA compliant materials
Process temperature	To 100 C
Process pressure	To 100 psi
Process line size	3-inch
Installation	Tri-clamp
Calibration	As required
Maintenance	As required

Conductivity Sensing Profile 2: Global Juice Manufacturer

A global juice manufacturer was seeking a solution for maintaining product consistency and reducing costs for processing and bottling operations, including CIP procedures. As the juice passed through the process line, the conductivity loop displayed a product value of approximately 3500 microsiemens. At the end of the bottling cycle the line is flushed out with a CIP solution.

This manufacturer chose a Foxboro 871FT Sanitary Flow-through sensor, for the following reasons:

- Flow-through design allowed in-line calibration while the process is running, which is critical for sanitary applications. An additional benefit is that the process line does not have to be opened to access the sensor, thus eliminating the need to have to recertify the process line as sanitary
- Virgin PEEK composition met both 3A sanitary certification and FDA compliancy certifications, and would be compatible with all binary solutions encountered
- Wide selection of bore sizes (½”, ¾”, 1.0”, 1½”, 2.0”, 3.0” or 4.0”) meant that it could be matched to the process line size, without need to replace or expand the existing line
- Better than 16 micro-inch interior bore finish would compliment the high volume, high frequency production
- Maximum temperature rating could easily withstand the process conditions
- Tri-clamp connection met 3A sanitary requirements
- Non-invasive strategy presented zero profile to the flow/product, and required very minimal maintenance
- Conductivity range capability from ~10 microsiemen/cm to 2000 millisiemen/cm, easily accommodated the required conductivity range for the product, CIP (NaOH), and rinse water used in the application
- Calibrated in less than ten minutes, without opening the process line or stopping the process flow, and with only a shirt pocket tool added significant additional benefits
- The multiple application and Auto Switching feature of the electronics provided a key capability for the process control required

Following are the specific parameters for the application:

Product	Fruit Juice
CIP	NaOH 1.5 - 3.5% by weight
Rinse	< 1,000 microsiemens/cm in pipeline
Certification	3A required
Process temperature	< 100 C
Process pressure	<150 psi
Process line size	2-inch and 3-inch
Installation	Tri-clamp
Calibration	On-line
Maintenance	Minima

With the flow-through sensor in place as an integral part of the pipeline, it immediately recognizes the change in conductivity from product to the CIP solution (commonly sodium hydroxide - NaOH). The system automatically switches to the correct curve (such as NaOH @ 50 C) and accurately measures conductivity during the CIP cycle.

The arrival of the rinse water causes the conductivity to drop sharply and the correct curve is automatically applied (such as Dilute NaCl) via the Auto Switch feature and the system continues to measure the rinse cycle. When the conductivity rises to the predetermined level of product (such as juice) the process Auto Switches to that specific application set, monitoring the product withthe appropriate curve set, and then when conditions dictate, again Auto Switch to the CIP curve set, and the process starts all over. The completely automated conductivity loop is the cornerstone to automating the valve-switching network to improve production efficiency and quality control, while reducing material waste and maintenance.

Conductivity Sensing Profile 3: Global Bottled Water Manufacturer

A global bottled water manufacturer was seeking a solution for maintaining product consistency and reducing costs for processing and bottling operations, including monitoring deionization of the process water, and ‘re-blending’ of the product water. As the water passes through the process line, the conductivity loop monitors and displays a product value targeting < 50 microsiemens. Once the water is sufficiently de-ionized the re-blending process begins, and selected ‘minerals’ are added while the flow-through sensor monitors the process conditions.

This manufacturer chose a Foxboro 871FT Sanitary Flow-through sensor, for the following reasons:

- Flow-through design allowed in-line calibration while the process is running, which is critical for sanitary applications. An additional benefit is that the process line does not have to be opened, thus eliminating the nee d to have to recertify the process line as sanitary
- Flow-through
- Wide selection of bore sizes (½”, ¾”, 1.0”, 1½”, 2.0”, 3.0” or 4.0”) meant that it could be matched to the process line size, without need to replace or expand the existing line
- Better than 16 micro-inch interior bore finish would compliment the high volume, high frequency production
- Maximum temperature rating could easily withstand the process conditions
- Tri-clamp connection met 3A sanitary requirements
- Non-invasive strategy presented zero profile to the flow/product, and required very minimal maintenance
- Conductivity range capability from ~10 microsiemen/cm to 2000 millisiemen/cm, easily accommodated the required conductivity range for the product in this application
- Calibrated in less than ten minutes, without opening the process line or stopping the process flow, and with only a shirt pocket tool added significant additional benefits
- The multiple application and Auto Switching feature of the electronics provided a key capability for the process control required

Following are the specific parameters for the application:

Product	Fruit Juice
CIP	NaOH 1.5 - 3.5% by weight
Rinse	< 1,000 microsiemens/cm in pipeline
Certification	3A required
Process temperature	< 100 C
Process pressure	<150 psi
Process line size	2-inch and 3-inch
Installation	Tri-clamp
Calibration	On-line
Maintenance	Minima

Conclusion

Selecting an invasive electrodeless sensor for a sanitary application would require compromises to low measurement capability and, if a retrofit, to the potential process lines size. In addition and by default, choosing the invasive approach relegates the end user to a more frequent and lengthy maintenance and calibration schedule, which involves exposing the sanitary line to the environment.

Non-invasive, flow-through technologies offer a significant advantage; the sensor becomes a section of the sanitary line. The bore size may be sized to match the process line, and since the sensor is a section of the line, there is no profile to show to the process flow.

Once the critical application and installation factors are determined, an understanding of conductivity sensing options will allow the best match of the appropriate conductivity technology for sanitary requirements.

Selecting the appropriate conductivity sensor has contributed to assured product quality and improved production efficiencies in sanitary production processes ranging from bottled water to proprietary pharmaceutical solutions. The key is in knowing your process, understanding conductivity technology, and taking the initiative to explore the benefits of flow-through conductivity sensing.

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December, 2015
Document Number FD-WP-A-001