October 31, 2006

JF-1A FUEL CONDUCTIVITY SENSOR
Technical Application Note 06-003

Measurement Stability

Background

The D-2, Inc. JF-1A in-line conductivity sensor is designed to provide high-accuracy, continuous measurement of conductivity of distillate fuels in flowing and non-flowing applications. In some installations it has been noted by users that the conductivity value reported by the sensor is variable or “fluctuates”. This application note discusses the various sources of measurement variability and mitigating steps to provide stable readings for conductivity measurement and automated additive injection control.

Sensor Measurement Principle

The D-2 JF-1A conductivity sensor uses a probe consisting of two concentric electrodes. When the probe is immersed in fuel, a very low frequency AC voltage is applied to the electrodes. Conduction through the fuel results in an AC electrical current that is amplified, detected, and output as either direct serial ASCII data, or as a standard 4-20 mA industrial current loop. The use of a precision AC voltage overcomes problems associated with electrode polarization, impedance, and residual DC charges allowing the sensor to accurately measure conductivity in flowing fuel. ASTM method development testing (round-robin) has demonstrated accurate, highly stable conductivity measurement in fuels flowing up to 30 ft/sec.

Then why is the measurement seen to be variable in some applications?

There are several physical conditions that can cause fluctuations in conductivity reading, even though the JF-1A sensor is correctly calibrated and functioning properly. Each of these, along with proposed solutions, is discussed below.

Since the JF-1 measures the actual conductivity of flowing fuel as the fuel passes the sensor, the sensor will measure the true fluctuations in conductivity of the fuel. In applications where fuel is not well mixed with conductivity enhancer additives, the sensor will measure fluctuations in conductivity due to the true variability of conductivity value in the flowing stream.

While additives (such as Stadis® 450) do tend to mix quite quickly into fuels, there needs to be sufficient residence time and mixing phenomena (elbows, static mixers, valves, etc.) to allow the additive to reach a uniform concentration within the fuel. Since the conductivity enhancer or static dissipation additive (SDA) tends to be highly concentrated (typical dose rate is 1 ppm), fuel that is not uniformly mixed with additive can exhibit localized conductivity values that may differ by several orders of magnitude.

Slow Pulse Injection Rates (the “Slug Effect”)

Consider a typical high-flow scenario with a 12” in diameter line flowing at 5,000 bph (220 lit/sec). This would result in a line velocity of 10 ft/sec (~3 m/sec). At a 1 ppm dose rate, the injection of SDA to control conductivity at around 100 CU (pS/m) would be 0.22 ml/sec. Most commercial injection systems have a minimum injection pulse

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volume of several ml. So let's consider a 4 ml injection pulse. That would mean an injection rate of 1 pulse/20 sec (if undiluted additive is used). That would mean approximately 19 seconds of "untreated" fuel would pass the sensor between each "slug" of highly dosed fuel.

At first we could consider that the average over a lengthy period would provide a relatively accurate reading, but this may not be a valid assumption. Consider that when a 4ml "slug" of SDA is injected into the flow it will dissipate over some length of pipe, let us say approximately 1 ft initially. In the 12" diameter example, the "instantaneous volume" of fuel being dosed with the slug would be 0.78 cf (22 lit). If conductivity value is linearly proportional to SDA concentration, the approximate conductivity of this "slug" would then be about 2,000 CU or 20 times the "average" conductivity. Nominally an average over 20 one-second samples would yield the 100 CU average, but two problems may occur.

First, and probably most important, is that in short pipe runs the SDA never truly dissipates through the fuel and there may be periods of a delivery where fuel is below the minimum specification for conductivity (creating a potential safety hazard).

Second, if the sensor is set to output conductivity value over a nominal range of 0-500 CU (typical set-up scenario), the high-conductivity "slugs" simply appear as over-scale and are "clipped" at the full scale value, rather than the true much higher conductivity value. Therefore, the calculated average can be biased accordingly. Note that the JF-1A internal averaging is over a much broader CU range than the upper limit of the 4-20 mA output (typically 0-1,500 CU) so it is important to average internally to the sensor rather than externally (using the 4-20 mA signal) to minimize this biasing effect. This is discussed in more detail below.

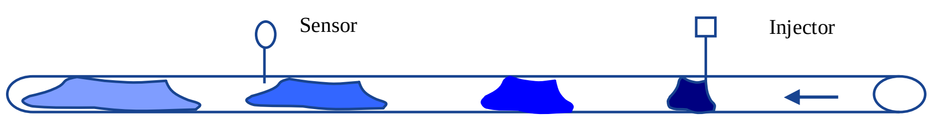

Figure 1: The "Slug Effect" Created by Slow-Pulse SDA Injection

Increased Injection Rate

So what can be done to improve measurement and control stability?

First it is important to increase the additive injection rate to a uniform rate (typically 0.5 to 2 Hz). This can be done by choosing injection pumps with smaller volumes (such as is done with the D-2 AI-1 injection system) that are designed for continuous injection, or by diluting the SDA so injection of larger volumes may be more continuous. In the example given above, a pre-injection dilution ratio of 20:1 (fuel:additive) would allow an injection rate of 1 Hz . However, it now becomes extremely important to assure that dilution is consistent, performed properly and pre-mixed additive/fuel remains stable.

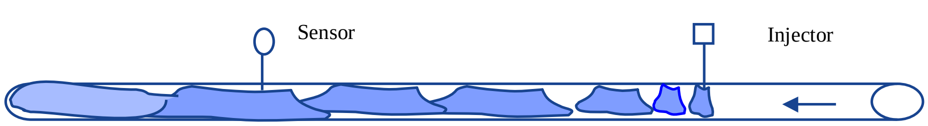

Figure 2: More Uniform Conductivity with More Continuous Injection

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Lower Flows

As mentioned above, smaller injection volumes and additive dilution are two methods that allow more rapid SDA injection rates and, therefore, more uniform conductivity values. This problem becomes more difficult to solve, however, as flow rates become smaller. In the example given above, the flowrate was a relatively high 5,000 bph. Now let us consider a typical truck terminal where flow rates for a 6 inch line may not be more than 500 gpm (31 lit/sec) and may be as low as 50 gpm (3.1 lit/sec) during load-start conditions. In this example, the line velocity would range from about 0.6 to 6 ft/sec. Even with a 40:1 dilution ratio, the injection rate for a 4 ml injection pulse would be only 1 pulse/3.2 sec at the high flows and 1 pulse/30 sec at the low flows.

One solution for these lower flows is to increase the dilution ratio to something like 100:1. This will improve the high flow measurement stability, but the "slug" problem described above will still exist at the lower flows. The best option to handle the low-flow scenario is to have a much smaller injection volume or to provide a blending solution. The D-2, Inc. AI-1 injection systems utilize precision injection pumps (and proprietary injection nozzles) that are cable of injection as little as 0.05 ml/stroke with stroke rates up to 3 Hz. These pumps allow precise control of additive and, in most cases undiluted additive may be used. Other systems may provide a needle-valve type blending option.

If small-volume rapid injection or precision blending is not possible with the injection system selected for a particular application, the other two options for low-flow start-up scenarios would be to set a fixed injection rate and just ignore fluctuations in conductivity reading, or to increase the internal averaging constant in the JF-1A conductivity sensor. The JF-1A has the ability to output average conductivity value rather than the instantaneous value. The user can select the averaging period using the RS-232 set-up menu for the sensor. This is preferred to external averaging as the sensor can average values over its entire measurement range (typically 0-1,500 CU) rather than its 4-20 mA output range (typically 0-500 CU), which will help eliminate bias errors due to "clipping" when measuring of high-conductivity "slugs". Care should be taken when adjusting the averaging rate, however, to assure that the averaging period is not so great as to render the sensor slow to respond to true changes in fuel conductivity.

In each application, regardless of the brand or type of injection system on-site "tuning" of the system will be required to allow the system to perform properly over all operating ranges. When planning system installation it will be important to include sufficient time to operate any injection system across the entire operating range so averaging constants, injection rates, and PID parameters may be selected that cover all possible operating scenarios.

Axial Mixing and Sensor Location

With relatively continuous injection, the time-related aspect of mixing or "slug-effect" can be eliminated but the additive or additive mix must still be thoroughly mixed with the fuel prior to measurement.

Consider a theoretical example where a steady stream of additive is injected near the pipe wall into a pipe with laminar flow and little mixing occurs. In this case, the fuel near the pipe wall would have very high conductivity and the conductivity value would decrease moving across the pipe. Fortunately two effects come into play to help. First in actual applications the flow tends to be highly turbulent and second, the SDA tends to dissipate quickly within the fuel. It does take some time, however, for this mixing to occur. The time (or distance downstream) for complete mixing will be a function of the Reynolds number and the specific piping configuration. In some cases it may be many pipe diameters downstream before complete mixing occurs. Since the JF-1A measures the actual conductivity of the fuel passing the sensor tip, in a stream where the additive is not well mixed with the fuel, the sensor will measure these actual fluctuations in conductivity.

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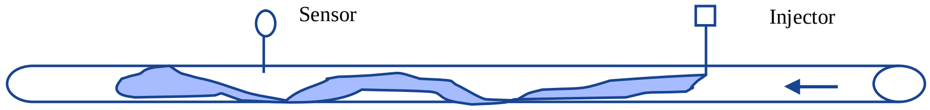

Figure 3: Poor Axial Mixing

To assure uniform conductivity measurement, the sensor should be placed well downstream of the additive injection point. If the sensor were placed at a location 100D plus downstream of the injection point, in most cases uniform mixing could be assumed. However, for automated injection system feedback control purposes, it is desirable to minimize the lag time (improve response time) between additive injection and conductivity measurement. So placing the sensor well downstream of the injection point, where it may take many seconds to “see” changes in conductivity, would be undesirable.

Distances can be minimized between injection point and measurement point by the addition of elbows, valves, strainers or in-line static mixers. If a static mixer is chosen, it is important to review the design of the mixer to assure that it mixes effectively across the entire pipe and does not leave unmixed void areas.

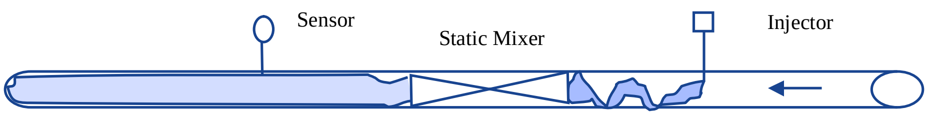

Figure 4: Improved Axial Mixing with In-line Static Mixer

Actual selection of a suitable measurement point may be a process of trial and error. In some systems 10D downstream of the injection point may be sufficient and in others a location as much as 50D may be required. As a general rule, with highly turbulent flow in pipes where there are at least two 90 deg elbows between the injection and measurement points, a separation of 20D is typically sufficient.

Summary

The JF-1A offers the ability to measure true fuel conductivity in-line, in real time. It is a highly accurate and stable instrument that can be used for quality management, alarm capability and as a feedback sensor for automated SDA injection.

It is important to understand that since the JF-1A is a real-time, in-line sensor it will measure the actual conductivity as the fuel comes in contact with the sensor. If the fuel conductivity is not consistent and uniform the sensor will measure these actual changes in conductivity.

Care in SDA injection system design, sensor placement and sensor set-up can prevent frustrating fluctuations in conductivity reading that can make fuel quality management and automated SDA injection difficult, if not impossible.

If you are experiencing any of the above phenomena or are considering installation of a JF-1A conductivity sensor or automated SDA injection system, please contact D-2, Inc. to discuss your particular application. We are pleased to provide installation and configuration recommendations that will help assure a trouble-free application.

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