

Heat Exchanger Leak Detection Using Conductivity and pH

Introduction

Many industrial processes use heat exchangers to cool process fluids. Wherever cooling water is used to cool a process fluid, there is a risk that leaks can develop. Leakage of the process fluid into the cooling water stream represents a loss of product and can be a source of fouling or corrosion in the cooling water system. Conversely, leakage of the cooling water into the process fluid can be a source of contamination. Early detection of heat exchanger leaks can minimize maintenance expenses and process upsets.

Heat exchanger leaks create measurable changes in the concentrations of the fluids on each side of the heat exchanger. Therefore, they can be detected in real-time using pH or conductivity measurements. The choices of whether to use a pH sensor or a conductivity sensor, where to install the sensor, and whether to use one sensor or multiple sensors depend on the application and should be made with the goal of ensuring a sufficient signal-to-noise ratio to detect a leak while minimizing cost of ownership.

Leak Detection Using Conductivity

Conductivity sensors require less frequent maintenance and calibration than pH sensors. Therefore, they are the preferred choice for leak detection in any application where they can provide sufficient signal-to-noise ratio.

The primary factor that determines whether a conductivity sensor will provide sufficient signal to noise ratio is the difference in conductivity between the fluid stream being monitored and the potential contaminant. For reasonable leak detection sensitivity, the conductivity of the contaminant should be at least 100 times greater than that of the fluid being monitored.

Other factors that influence signal-to-noise ratio include:

1. The conductivity range of the uncontaminated fluid.
2. The rate at which conductivity changes in the uncontaminated fluid.
3. The transit time between the potential leak source and the measurement point.

Wide ranging and rapidly changing conductivity in the uncontaminated fluid and long transit times between the leak point and the measurement point make leaks harder to detect.

Leak Detection Using One Conductivity Sensor

The conductivity of an uncontaminated sample normally varies between a high and low extreme. The worst case for leak detection with a single sensor is when the sample conductivity is at its



minimum because at this time there is the highest possibility that a leak could occur without the conductivity increasing beyond the normal range for the process, resulting in the leak being undetected. Given this fact and the dependence of sensitivity on the ratio of the sample conductivity to the contaminant conductivity, the overall sensitivity (S_s) with a single sensor can be estimated from the following:

$$S_s = \frac{K_H - K_L}{K_C}$$

Equation (1)

where S_s is the sensitivity in volume of contaminant per volume of sample; K_H and K_L are the maximum and minimum normal sample conductivity; and K_C is the contaminant conductivity. Sensitivity with a single sensor is limited by the normal variations in sample conductivity. The alarm for leak detection should be set at approximately 5% full scale above the maximum normal conductivity or other reliably measurable conductivity increase.

Leak Detection Using Differential Conductivity

The use of two conductivity sensors, one before the potential leak source and one after it, can allow for changes in sample conductivity to be canceled out by looking at the difference in the two measurements. In theory, any conductivity difference measured between the two sensors should indicate a leak. In the real world, however, the rate at which conductivity changes in the uncontaminated sample, the lag time between the leak point and the measurement point, and the normal measurement error between the two sensors will limit the sensitivity.



When the normal conductivity change in the sample is much slower than the transit time, both sensors in a differential conductivity measurement are seeing essentially the same sample and variations in the sample conductivity are effectively cancelled out. But measurement errors in both measurements will cause the differential conductivity to vary above and below zero, by twice the error in each measurement. The sensitivity can be estimated from the following formula, based on the worst-case conditions:

$$S_D = \frac{4e}{K_L} * \frac{K_H}{K_C}$$

Equation (2)

where S_D is the sensitivity in volume contaminant per volume sample; e is the estimated measurement error in conductivity units ($\mu\text{S}/\text{cm}$ or mS/cm); K_L , K_H , and K_C are the minimum and maximum sample conductivities and contaminant conductivity respectively. Since the error in measurement is much smaller than the conductivity variations, leak detection sensitivity with differential conductivity is much better than with a single sensor.

When the rate of sample conductivity change is faster than the transit time between the leak source and the measurement point, the differential conductivity without any leak can be significantly positive or negative. In the extreme case, where the sample conductivity can change from its normal maximum to minimum in a period of time shorter than the transit time, a leak which would be detected using a single sensor on the outlet could go undetected using differential conductivity. A single sensor after the potential leak source is the best choice in these cases.

Leak Detection Using Conductivity Sensors – Additional Considerations

Accurate temperature compensation is important. Some processes have large temperature fluctuations. When using differential conductivity for leak detection, temperature differences can exist between the two measurement points. Inaccurate temperature compensation can give false indications of leaks or mask real leaks.

If the sample and the contaminant are both concentrated solutions, the possibility that they could react upon mixing or that the conductivity of the mixture may not be additive should be considered. The best course of action in this case is to titrate the sample with the contaminant and measure the conductivity response. The conductivity change at a particular volume to volume ratio of contaminant to sample can be used to estimate sensitivity.

Leak Detection Using pH

For applications where there is not enough signal-to-noise ratio to reliably detect a leak using conductivity, leak detection using pH may be a good alternative.

For a leak to be detected by pH, a small amount of contaminant must cause a measurable change in the pH of the sample being monitored. In general, when the process fluid being monitored has a pH that is near neutral (pH 7.0), leaks are easier to detect. However, leak detection sensitivity depends upon the pH and composition of both the process fluid and the contaminant.

Leak Detection Using pH in Non-Buffered Fluids

In dilute samples or in samples without buffering action, the pH response can be easily predicted. Table 1 shows the best sensitivity of leak detection possible for various sample and contaminant pH values. The sensitivities are given in terms of the volume fraction of the leak detectable, expressed from percent (%) through parts per billion (ppb), by volume. For estimating sensitivity, the normal pH range of the sample and the contaminant must be considered. The maximum and minimum pH of each should be checked against one another and the poorest sensitivity should be used for estimation.

Leak Detecting Using pH in Buffered Fluids

Samples containing weak acids and bases have weak pH response, which reduces the sensitivity of leak detection. This is due to buffering action, which is the tendency of a solution to resist pH changes. The degree to which this occurs depends on the concentration of the acids, bases, or salts and the sample pH range. Examples include acetic acid (CH_3COOH), hydrofluoric acid (HF), ammonia (NH_3), sodium carbonate (Na_2CO_3), and sodium sulfate (Na_2SO_4). It is often difficult to predict just how the sample pH will respond in such mixtures, so a volume of the sample should be titrated with the contaminant. The volume of contaminant required to cause a reliably measurable pH change (± 1.0 pH) divided by the volume of sample titrated will give the sensitivity. As an initial check, Table 1 can be consulted to see if there is the possibility of acceptable sensitivity before titration.

Leak Detection Using One pH Sensor

For a leak to be reliably detected, the pH threshold for leak detection must be significantly larger or smaller than the fluid's maximum or minimum pH without a leak. The sensitivities in Table 1 were based on ± 1.0 pH above or below maximum or minimum pH as a reliably measurable change. Using the poorest sensitivity based on the maximum and minimum pH of the sample and contaminant ensures that the actual sensitivity will be equal to it or better.

Leak Detection Using Differential pH

Differential pH involves using two pH sensors, one before the potential leak source and one after. The difference in pH is measured and used to detect the leak (Figure 1). The benefits and limitations of leak detection using differential measurement are the same for pH and conductivity and are described in the section on leak detection using differential conductivity.

Table 1 - Estimated sensitivity for unbuffered samples and contaminants at various pH values. Sensitivity is shown at a pH change of ±1.0 pH

Contaminant pH	Sample pH												
	1	2	3	4	5	6	7	8	9	10	11	12	13
10 Molar Acid		9.0 ppT	900 ppm	90 ppm	9.0 ppm	0.9ppm	1.0 ppb	90 ppb	0.9 ppm	9.0 ppm	90 ppm	900 ppm	9.0 ppT
1 Molar Acid			9.0 ppT	900 ppm	90 ppm	9.0 ppm	10 ppb	0.9 ppm	9.0 ppm	90 ppm	900 ppm	9.0 ppT	9.0 %
1				9.0 ppT	900 ppm	90 ppm	0.1 ppm	9.0 ppm	90 ppm	900 ppm	9.0 ppT	9.0 %	
2					9.0 ppT	900 ppm	1.0 ppm	90 ppm	900 ppm	9.0 ppT	9.0 %		
3						9.0 ppT	10 ppm	900 ppm	9.0 ppT	9.0 %			
4							100 ppm	9.0 ppT	9.0 %				
5							1.0 ppT	9.0 %					
6							N/A						
7							N/A						
8							N/A						
9							9.0 %	1.0 ppT					
10					9.0 %	9.0 ppT	100 ppm						
11				9.0 %	9.0 ppT	900 ppm	10 ppm	9.0 ppT					
12			9.0 %	9.0 ppT	900 ppm	90 ppm	1.0 ppm	900 ppm	9.0 ppT				
13		9.0 %	9.0 ppT	900 ppm	90 ppm	9.0 ppm	0.1 ppm	90 ppm	900 ppm	9.0 ppT			
1 Molar Base	9.0 %	9.0 ppT	900 ppm	90 ppm	9.0 ppm	0.9 ppm	10 ppb	9.0 ppm	90 ppm	900 ppm	9.0 ppT		
10 Molar Base	9.0 ppT	900 ppm	90 ppm	9.0 ppm	0.9 ppm	90 ppb	1.0 ppb	0.9 ppm	9.0 ppm	90 ppm	900 ppm	9.0 ppT	

% = percent, ppT = parts per Thousand, ppm = parts per Million, ppb = parts per Billion

Figure 1 - Heat Exchanger Leak Detection Process



The Emerson Solution

The appropriate conductivity or pH sensor for a leak detection application will depend on all the usual considerations of temperature, pressure, and process fluid composition.

To measure conductivity, the [Rosemount™ 400 Contacting Conductivity Sensor](#) is a good choice for most applications. For higher conductivity fluids or fluids with potential to cause fouling or corrosion, the [Rosemount 228 Toroidal Conductivity Sensor](#) is appropriate.

To measure pH, the [Rosemount 3900 pH Sensor](#) is a good choice for most clean process fluids. For leak detection in ultra-pure water such as boiler feedwater, the combination of the 3900 sensor with a low flow panel is an excellent solution.

All of these sensors are compatible with all Rosemount liquid analysis transmitters, including the [Rosemount 56 Dual Channel Transmitter](#) which offers dual sensor inputs, a large full color display, four alarm relay outputs, and built-in measurement and troubleshooting tips.







Rosemount 400 Contacting Conductivity Sensor



Rosemount 3900 pH Sensor

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