ACCURATE MEASUREMENT OF WATER IN FEEDWATER HEATERS

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ACCURATE MEASUREMENT OF WATER IN FEEDWATER HEATERS

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ABSTRACT

The accurate measurement of liquid levels in power plant operations is key to efficient operation. Although water is a liquid that can be easily measured by numerous measurement technologies, detection in applications like feedwater heaters, for example, takes on a range of complexity that stresses even the most robust devices.

Feedwater heaters operate in various ranges depending upon the stage of the process. High-pressure heaters typically operate at 1030 psig @550^{0}F (71 bar @288^{0}C). Further, liquid level transmitters should operate ideally from ambient start-up to operating conditions at full capacity; a wide variation.

Torque tube and differential pressure transmitters have been the technologies of choice for many years, each technology having a set of strengths, weaknesses and idiosyncrasies. Performance of both technologies are dependent on the Specific Gravity (SG) of the medium of they are measuring; both suffer inaccuracies when the SG of water varies over temperature.

A new level measurement technology, Guided Wave Radar (GWR), has emerged that eliminates the issues that have plagued torque tube and DP transmitters. Guided Wave Radar (GWR) has shown to accurately measure the level of water throughout the changing conditions seen in the life cycles of vessels like feedwater heaters. GWR is a technology based on the speed of light, or more precisely, electromagnetic energy. Inaccuracies due to Specific Gravity (SG) variations are not an issue. In fact, Guided Wave Radar has shown to accurately measure media with wide variations in dielectric.

Key Words/Terms
Guided Wave Radar (radar)
Level measurement (level)
Feedwater heaters (feedwater)
Specific gravity (density)

INTRODUCTION

Guided Wave Radar (GWR) is a new technology to the Industrial Level Measurement market. Although it is new to level measurement, it is based upon the well-proven principles of Time Domain Reflectometry (TDR). TDR has been used for decades detecting cable breaks in large buildings and underground installations. Recent breakthroughs now make it possible to manufacture a Guided Waver Radar transmitter that is both inexpensive and low power. This new transmitter offers significant advantages over the well-established approaches such as torque tube and differential pressure transmitters.

NOMENCLATURE

DP = Differential Pressure (transmitter)
ε = dielectric constant
c = speed of light
GWR = Guided Wave Radar (transmitter)
SG = Specific Gravity
TDR = Time Domain Reflectometry

APPLICATION: WATER LEVEL MEASUREMENT IN FEEDWATER HEATERS

For many years the power industry has struggled with accurate measurement of water level in feedwater heaters. Power plants have lived with the inherent inaccuracy of available level transmitter technology. What on the surface seems a simple task becomes difficult in actual practice. Water and water-based media are the most common form of level measurement applications in the industrial market. At ambient conditions water has a strong, stable Specific Gravity (SG), high dielectric constant, and is not considered highly corrosive. However, the properties of water change significantly as temperatures increase.

Feedwater heaters, as the name implies, serve the function of pre-heating the boiler feedwater by the efficient utilization of waste heat. They are often installed in series to stage the increase in water temperature. Common operating pressures for these heaters range from approximately atmospheric to 1030 psig (1-71 bar). Since the system is typically operated at saturated conditions, the corresponding process temperatures follow the saturated steam curve as shown in Figure 1.

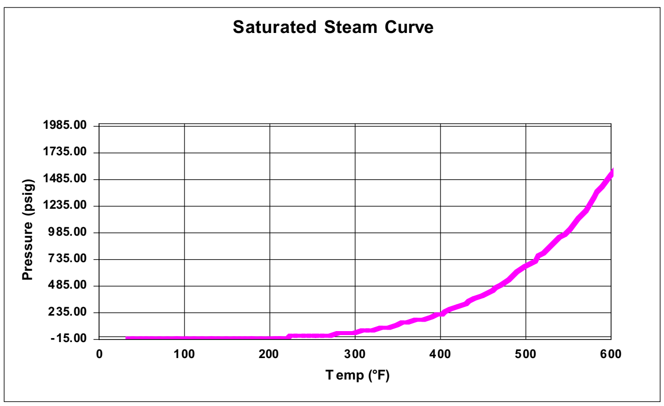

Figure 1. Saturated Steam Curve

These temperature values show the typical heaters will operate in a range of 70^0F (21^0C) @atmospheric pressure during startup, to 550^0F @1028 psig (288^0C @71 bar) in normal operation. Further, conditions can vary on a daily or even hourly basis depending on changes in boiler load. Herein lies the problem for typical level measurement technologies. Key properties of water vary considerably with the change in temperature. As Figure 2 reveals, specific gravity drops with an increase in temperature.

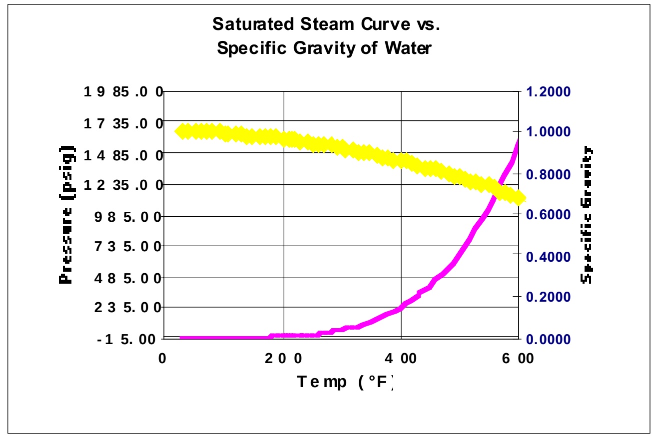

Figure 2. Saturated steam curve vs. specific gravity of water.

The Specific Gravity (SG) of water at 70F (21^0C) is 0.998. The SG falls to 0.963 @200F (93^0C); 0.857 @400F (204^0C) and to 0.736 @550F (288^0C).

Why is this important?

PRESENT LEVEL MEASUREMENT TECHNOLOGIES

Torque Tube transmitters have been used to measure feedwater heater water level for many decades. It has been a stalwart part of the power industry; a robust device that has been depended on for reliable measurement. Its measurement is based on the buoyancy principle first explained by the Greek Archimedes of Syracuse in approx. 250 BCE:

Archimedes' principle states that a body wholly or partially immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced. By detection of the apparent weight of an immersed displacer, a level instrument can be devised. If the cross-sectional area of the displacer and the density of the liquid are constant, then a unit change in level will result in a reproducible unit change in displacer weight. The simplest level device of this type involves a displacer that is heavier than the process liquid and is suspended from a spring scale. When the liquid level is below the displacer, the scale shows the full weight of the displacer. As the level rises, the apparent weight of the displacer decreases, thereby yielding a linear and proportional relationship between spring tension and level. The spring scale can be calibrated 0 to 100 %, or in other units. [1]

Torque tube transmitters use a displacer suspended in the liquid to determine level. The displacer length is related to the span of the 4 and 20 mA points. They are commonly used in chamber or cage applications mounted off the side of the vessel. The position of the side/side or side/bottom process connections of the chamber/cage determines the mA span and, therefore, the displacer length. A stable Specific Gravity (SG) is critical to consistent accuracy and reliable output.

Pressure/Differential Pressure transmitters are also a popular measurement technology utilized in feedwater heater level measurement. It is one of the most ubiquitous of all measurement technologies. No other technology can be used for three of the major measurement parameters: pressure, flow and level. Pressure/DP transmitters infer liquid level by measuring hydrostatic head pressure. DPs, however, suffer the same weakness as torque tube transmitters- inaccurate measurement due to instability of the Specific Gravity (SG) of the medium.

In order to obtain an accurate measurement using d/p cells, the densities of the process liquid and of the reference leg must be known and constant. [2]

Figure 3 shows the error associated with a displacer or DP transmitter when specific gravity varies due to change in temperature.

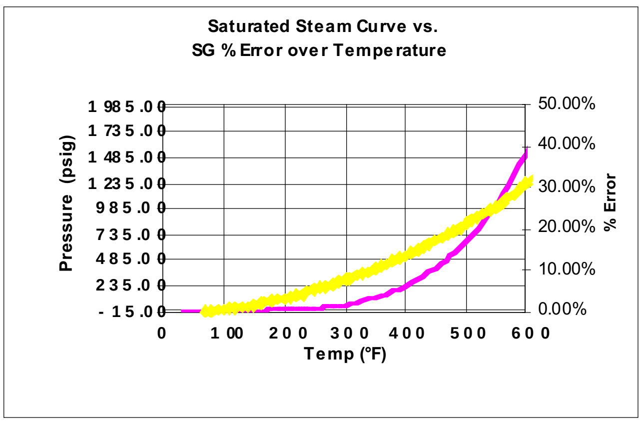

Figure 3. Saturated steam curve vs. % error of specific gravity variation of water.

Often displacer and DP transmitters are calibrated on a bench to ambient/atmospheric conditions. Assuming 0 error at 70^0F (21^0C), error increases proportionately with increasing temperature. At 200^0F (93^0C) error equals 3.2%, at 400^0F (204^0C) it is 13.5% and increases to 25.9% at 550^0F (288^0C). Often this error has been accounted for by calibrating the instruments to a specific operating condition, for example, the specific gravity at 400^0F (204^0C). This is helpful in establishing performance at a specific temperature but does not eliminate the error when temperatures vary from that given point.

DP transmitters add further complications to their use. Chemical seals and filled systems needed for monitoring in the elevated temperatures of power plant applications further degrade performance.

A larger and less predictable error can result from the temperature-sensitive nature of the seal and capillary system. Temperature differences between the low and high side will cause differing amounts of thermal expansion; this will be sensed by the d/p cell as a differential pressure and interpreted as a level change. Because the unequal amounts of expansion can be caused by the process temperatures or by changes in the ambient conditions, it is not always possible to zero out this error. [3]

Is there a better way?

GUIDED WAVE RADAR- THEORY OF OPERATION

Guided Wave Radar (GWR) is based upon the principles of Time Domain Reflectometry (TDR).

TDR is a pulse sampling technique that characterizes the distributed electrical properties of transmission lines. TDR instruments launch low amplitude, high frequency pulses onto a transmission line, cable, or waveguide under test and then sequentially sample the reflected signal amplitudes. Typically, the reflected pulse amplitudes are displayed on a calibrated time scale. In this way, cable impedance changes, and discontinuities can be spatially located and assessed. [4]

In GWR level measurement, the probe becomes the waveguide. The characteristic impedance of the probe is based on its configuration in air, $\varepsilon = 1.0$. A typical coaxial probe has an impedance of 50 ohms in air. Like the 75-ohm coaxial cable used in television today, it is an efficient propagator of high frequency (microwave) energy. The amplitude of the reflection from the level surface is directly related the impedance change on the probe/waveguide; the impedance change being related to the dielectric constant of liquid surface.

Dielectric is defined as a*n insulating material or a material that can sustain an electric field with very little dissipation of power.* [5]

Dielectric constant is defined as *a material characteristic expressed as the capacitance between two plates when the intervening space is filled with a given insulating material divided by the capacitance of the same plate arrangement when the space is filled with air or is evacuated.* [6]

For typical process media, the Dielectric scale ranges from 1-80. Water is considered a high dielectric medium with ε = 80 @70^{0}F (21^{0}C). A high dielectric liquid yields an extremely strong reflection as shown in the oscilloscope trace in Figure 4.

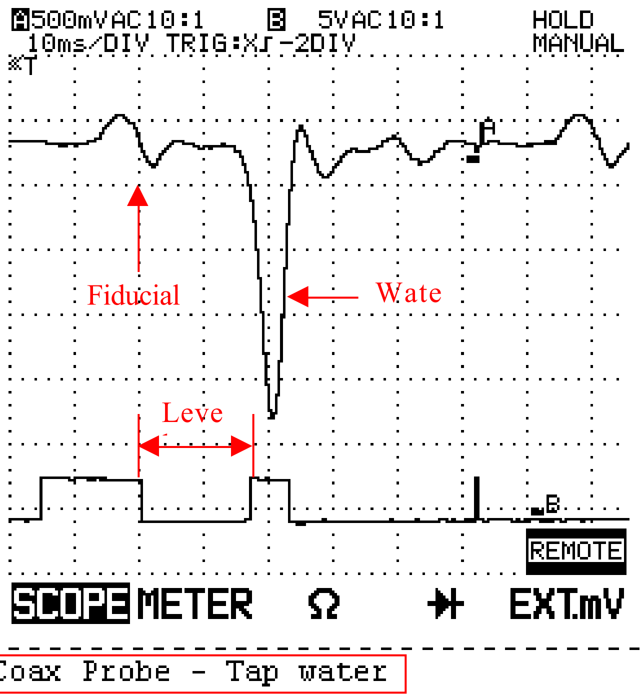

Figure 4. Oscilloscope trace of Guided Waver Radar showing Fiducial (baseline reflection) and strong reflection received from water (high dielectric medium).

The small Fiducial, or base-line reflection, is the zero point for the GWR measurement. A typical Fiducial is 200 mV. The large, negative level pulse is developed by the reduction in impedance in the waveguide from the presence of the high dielectric water. The higher the dielectric of the medium, the higher the amplitude of the reflection it creates. In this scope trace the high dielectric (ε = 80) water is approximately 2000 mV. Interestingly, the dielectric of water does change with temperature as shown in Figure 5.

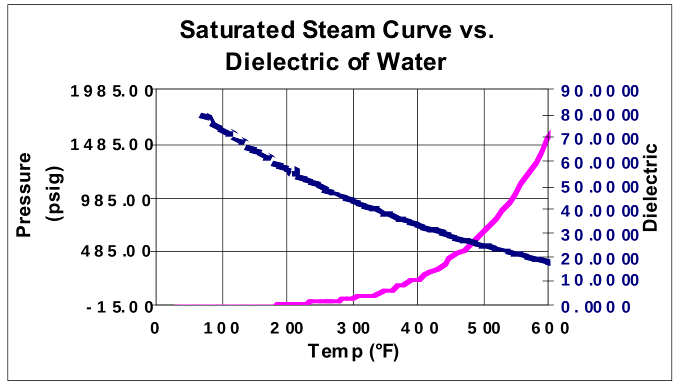

Figure 5. Saturated steam curve vs. dielectric constant of water.

Starting with ε = 80 @70^{0}F (21^{0}C), the dielectric of water drops to a value of 21.8 @550^{0}F (288^{0}C). At first glance this would appear to create the same potential for error as with the SG shift in the displacer and DP applications. However, this is not the case for Guided Wave Radar (GWR) devices as Figure 6 shows.

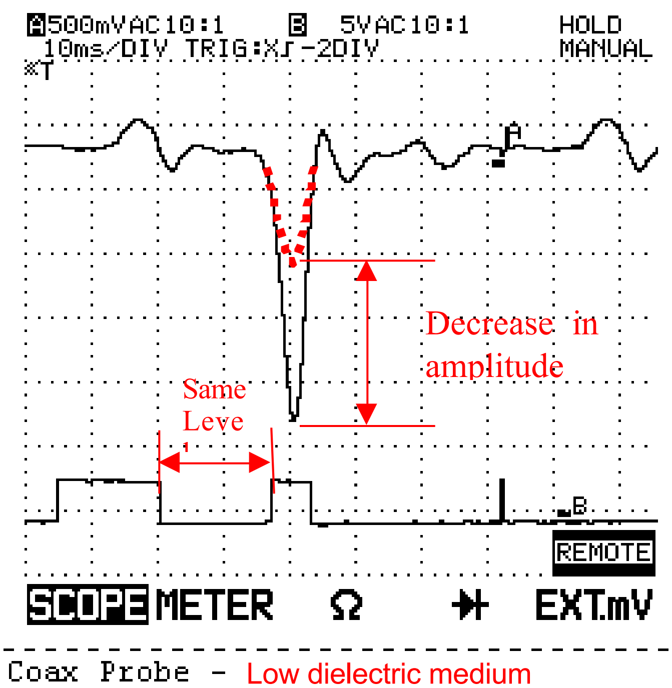

Figure 6. Oscilloscope trace showing reflection amplitude decreasing dielectric constant of liquid yet its point in time (position) remains constant.

The lower dielectric medium creates a reflected pulse with decreased amplitude; however, the reflection still exists at the same point in time (position) as the pulse with the larger amplitude. In Figure 6, a low dielectric medium (~750 mV) has been added to show the relationship to the higher dielectric (~2000mV). Dielectric of the medium, although important to the creation of a good reflection, is not critical to accurate measurement if it varies.

This stability of measurement has several key ramifications for users:

1.) Factory calibration can be achieved that frees the installing technician from the need of laborious on-site calibration. Often these transmitters are physically installed, have 24VDC applied and are used immediately. Field configuration to adjust 4mA and 20mA points is typically done to fine-tune to a specific vessel.
2.) As already discussed, GWR transmitters work reliably even in conditions of varying dielectric of the media.

A HIDDEN ISSUE?

There is one last subject worthy of discussion. There are now thousands of Guided Wave Radar transmitters installed worldwide; hundreds of these units installed in power plant applications. To date, no performance problems have been reported regarding speed of propagation issues. This is odd since theoretically it can be shown to be a potential issue.

Error can be introduced by speed of propagation variations related to the dielectric of the vapor space above he liquid. The high frequency, electromagnetic pulses travel at the speed of light. The speed of light (c) in a vacuum (ε = 1.00) travels at 186,000-miles/second or $3x10^8$ m/sec. Propagation speed is calculated as

$$c/\sqrt{\varepsilon} \qquad (1)$$

where c = speed of light
ε = dielectric constant of the vapor space

As the equation 1 shows, as long as the pulses travel in a vapor space with a ε close to 1.00, no significant variation in the speed of propagation is expected. Figure 7 shows the dielectric of steam vapor along the saturated steam curve.

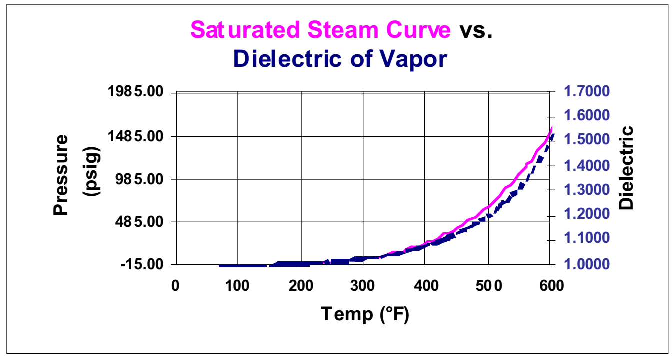

Figure 7. Saturated steam curve vs. dielectric of water vapor

Based on these values, potential error due to vapor space dielectric variations can be calculated. Comparing the square root of the dielectric to 1.00 reveals errors due to vapor space dielectric variations. These are shown in Figure 8 as percentage error.

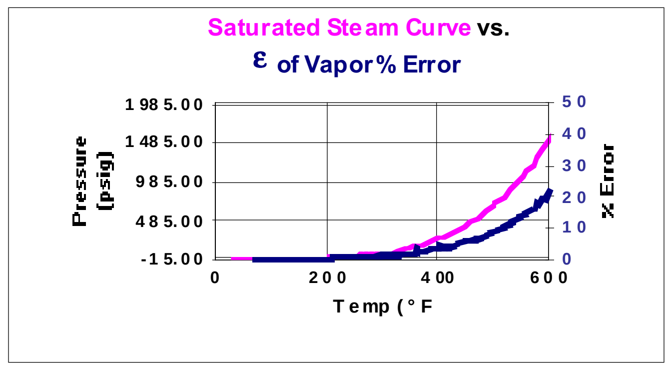

Figure 8. Saturated steam curve vs. % error of the dielectric constant of water vapor.

This is mentioned for discussion purposes only. Theoretically, there is error due to dielectric variation in the vapor space above the liquid particularly at elevated temperatures. However, although we can prove this in theory, thus far there have been no reported problems concerning vapor space dielectric and the performance of GWR in feedwater heater applications. One possible interpretation can be gained by comparing the percent error of Specific Gravity (SG) vs. per cent error of vapor space dielectric over temperature (Figure 9).

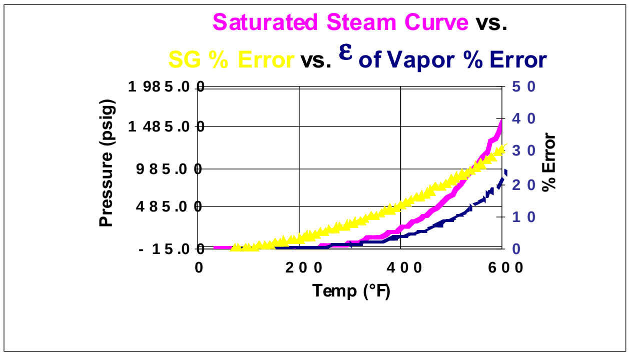

Figure 9. Saturated steam curve showing comparison % error specific gravity vs. % error dielectric of vapor space above liquid.

Errors due to the increase in dielectric of the vapor space remain small compared to errors associated with specific gravity variation. Changes in specific gravity cause large increases in error immediately upon its variation in temperature from ambient. Speed of propagation errors remain small throughout much of the temperature range.

This issue raises numerous questions. Is the error of Guided Waver Radar (GWR) transmitters present but going unnoticed? Are most feedwater applications operating at lower temperatures where the error is less pronounced? Is the data supplied us correct? Radar/Guided Wave Radar is still very new to the industry and we have much to learn.

CONCLUSIONS

Feedwater water level measurement is critical to the efficient operation of the modern power plant. Specific Gravity (SG)-based devices like Torque Tube and Pressure/DP transmitters have shown to be problematic. Variations in specific gravity due to temperature changes create significant errors in measurement. A new technology, Guided Wave Radar, is proving itself a worthy replacement. It has significant advantages over these existing technologies:

- Insensitive to variations in dielectric or Specific Gravity (SG) shift of the media; system will perform reliably from ambient/atmospheric up to full operating conditions.
- No moving parts to wear out and fail.
- No field calibration required; can be installed with simple configuration (menu) changes needed to adapt the transmitter to a specific vessel or media.
- Buildup/coating on probe causes minimal error.
- Cost-competitive to the existing level measurement technologies.
- Cost of Ownership is less than existing devices due to simple installation/configuration/commissioning costs and superior performance.
- Leak points are minimized to just one at the very top of the vessel.
- Its use is not limited to feedwater heaters; it is extremely versatile. GWR can be used just as reliably in cooling towers, fuel storage vessels, waste sumps and lubricant reservoirs.

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