MODERN INSTRUMENTATION FOR GEOTHERMAL WATER AND STEAM MEASUREMENT – A CASE STUDY ON ULTRASONIC FLOW, VORTEX FLOW, AND RADAR LEVEL

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Keywords: *Instrumentation, Flow, Level, Ultrasonic, Vortex, Radar, Guided Wave.*

ABSTRACT

As a geothermal steamfield evolves it is often necessary to retrofit and upgrade instrumentation to collect additional information for regulatory compliance, increase reliability or facilitate new process controls. Geothermal temperatures, scaling and chemical content have traditionally caused difficulty with instrumentation, and the tendency has been to limit instrumentation or use very simple devices (dP flow elements, mechanical level switches, etc.). This paper presents general information to consider when selecting new and novel instruments as well as a case study on the installation, use, issues and results of testing of several different types of devices including ultrasonic meters for brine flow, vortex meters for steam and brine flow, radar for weir box and drain pot level for process measurement and control at Contact Energy.

1. INTRODUCTION

1.1. Overview

Geothermal fluids are difficult to measure for multiple reasons. In brine, scaling can occur on measurement surfaces and tapping points relatively quickly, temperatures can melt devices normally designed for cold water service, and entrained gasses can often become trapped in impulse lines and disrupt measurements. In addition, the steam service process operates along the saturation line, which is traditionally avoided in other industries; this means steam instruments in geothermal power plants are often required to operate outside normal measurement limits. In addition, the H_2S in both the process fluid and the atmosphere can cause corrosion of sensitive electronic components.

Instrumentation also requires periodic maintenance and calibration, and for the instrumentation to remain accurate in geothermal fluid these maintenance periods must generally be more frequent in geothermal plants than in traditional power plants.

These difficulties have led designers to limit the amount of instrumentation in geothermal power plants and select only instrumentation which has previously been proven effective. Traditionally, a steamfield will have capacitive type pressure transmitters, differential pressures for level or flow, mechanical level switches and sometimes resistance temperature detectors (RTD) or thermocouple temperature devices.

At the same time, there is often a competing demand from operations, environmental, process and reservoir engineering to increase the amount of information collected. Drivers such as increased plant efficiency, new or increasing regulations and integration of new operational features are often drivers for changing or increasing instrumentation.

1.2. General Design Considerations

When selecting new instruments for geothermal service, some unique concerns and design considerations need to be addressed.

1.2.1. Scaling

Because of scaling, instrumentation should have limited or no moving parts in contact with the fluid. Additionally, small measurement passageways should be avoided. Small ports, such as those on a pitot tube, generally block with scale after a short period of time (less than 1 year). Scaling is generally a concern in both steam and brine systems.

Retractable/hot tap insertion type devices often become stuck when used in brine service unless they are frequently cycled in and out to knock off the scale, leading to broken retraction gears/linkages. Retractable devices have traditionally been successful in steam service, and are favourable as cleaning and maintenance can be performed without plant outages.

If moving parts and small passageways cannot be avoided, consideration should be given to regular preventative maintenance cycles or self-cleaning devices (such as instruments which have an air blowing sequence to clean internal passageways).

Scaling can be reduced by fully insulating or blanketing the device, as cold spots in piping often cause scale to form. If this is done, the user should ensure that the device is fully rated for the process temperature. Often the measurement portion of the device is rated for a higher temperature than the electronic portions are, so this difference must be taken into account. Remote-mount transmitters are one way to address this concern.

1.2.2. Tapping Points/Process Connections

Most instruments need some sort of connection to the vessel or pipe work, and several concerns in this area are specific to geothermal service.

Generally, if a process connection is needed in a scaling environment DN50 to DN80 are preferred, as DN25 and below are generally too small and can block easily.

The tapping points and assemblies should also be designed to be “rodded out” and cleaned. This means having a cross or tee in line with the tapping point to allow a glanded tool to be driven or drilled through while in service to dislodge scale. If this is not possible, such as on a bridle assembly, blow-down valves should be provided and regularly used to clear deposits.

It is also preferable to connect the instrument via a flanged surface instead of a threaded connection. If a threaded connection is required, the threads should be 316 stainless steel to prevent corrosion.

1.2.3. Process Corrosion and H_2S

The H_2S fluid and atmosphere present a challenge for both the wetted components and the electronics.

Additionally, no two fields have identical chemistry. Care should be taken to ensure that the devices and materials which are selected are compatible with the unique field chemistry. Previous use in other geothermal plants is usually a good indicator but not a guarantee of reliable service.

To avoid stress corrosion cracking, the wetted components should be specified as compliant with *NACE MR0175/ISO 15156 Petroleum and natural gas industries - Materials for use in H2S-containing environments in oil and gas production*. While this standard is commonly used in the petrochemical industry, some instrument manufacturers may not be familiar with it, in which case a careful assessment of the materials used in the construction of the components is prudent. Generally, materials meeting this standard are acceptable for geothermal environments, but field specific materials knowledge should take precedence.

1.2.4. Electronics Corrosion/Protection

Similar to the wetted components, the electronics often suffer from exposure to H_2S gas as well as damp steam environments.

IP67/Nema 6 rated enclosures generally provide good overall ruggedness for geothermal environments, as they are dust tight and water resistant to 1m. For extremely tough locations, such as those near an atmospheric vent or silencer, an IP69K rated enclosure, which is designed for high-pressure steam cleaning, might be prudent.

Whenever possible, instruments that have the electronics hermetically sealed and the field terminations in a separate compartment should be selected (Figure 1). This reduces the exposure of the electronics to H_2S during construction and servicing.

Figure 1: Hermetically sealed termination area, isolating the termination from the electronics. Also note the o-ringed sealed cap.

Conformal coating – a protective chemical/polymer film (typically about 50µm thick) that "conforms" to the printed circuit board – should be requested. This coating is applied to electronic circuitry to act as protection against moisture, dust, chemicals, and temperature extremes that, if the circuitry were left uncoated (non-protected), could result in damage or failure of the electronics to function. This is beneficial for preventing H_2S from corroding the circuitry. With this coating and a well-sealed device, per above ratings, potting (filling the electronics cavity with thermo-setting plastics, epoxy or silicone rubber gel), which can make maintenance and diagnostics difficult, is generally not necessary.

To prevent signal and power cables from corroding, the cables should be fully tinned. If the instrument manufacturer provides cables, such as those connecting a transmitter to a remote display, tinning should be requested specifically, as it is not normally provided.

2. VORTEX FLOW METERS

Vortex flow meters were first used to replace averaging pitot tubes (Annubars™), which had a history of fouling/blocking of the small pressure ports in steam service.

Vortex flow meters work by placing an obstruction, called a shedder bar or bluff body, in the flow path, and measuring the frequency of vortices occurring on each side of the shedder bar using a mechanical or piezoelectric sensor. The frequency with which these vortices alternate or pulse between the sides of the shedder bar is proportional to fluid velocity, which can be converted to volumetric flow given known pipe dimensions.

The first use of vortex flow meters at was in 2011 at Ohaaki. Since then, these meters have been used to successfully measure steam flow at approximately ten other locations at the Wairakei and Ohaaki steamfields.

2.1. General and Installation Concerns

Vortex meters are available as spool piece devices (generally for smaller pipe sizes) and as insertion type devices, where the meter is installed on a branch connection with the shedder bar and sensor protruding into the process pipe. Insertion type vortex flow meters cause limited pressure drop, making these meters an ideal candidate for retrofits where no previous meter was installed and an orifice plate or venturi would cause an unacceptable pressure drop.

Additionally, while having a higher device cost than a dP meter (approximately \$10-20k NZD vs. \$2-4k NZD), for large steam lines, when the overall installation cost of an orifice plate (e.g., flanges, welding, non-destructive evaluation, machined stainless plate, tapping points, dP meter) is factored in, a vortex meter is competitively priced.

Many of the commercially available vortex meters also contain a pressure or temperature sensor, which is used for compensating the measured flow values for energy density calculations. This means that many of these devices can act as a multi-process device, providing useful additional process data for minimal extra cost. These secondary values should not be used for alarms or process control, as these measurements are not adequately independent and usually cannot be calibrated the same way an independent pressure or temperature device can be.

2.2. Scaling

While no formal study has been conducted, empirical evidence from Wairakei Flash Plant 16 A and B shows that vortex meters are less prone to measurement degradation due to scaling in steam service than averaging pitot tubes are. At this flash plant, one meter of each type is installed in near identical instances with similar well chemistry (physically next to each other on identical diameter pipes and separation vessels). Experience by other operators has shown similar results (Learned, 2010).

While vortex meters are generally less prone to scaling issues, the buildup of scale on the shedder bar can and does cause changes in measured values (usually a decline in measured flow absent other process changes). For steam service, an initial annual cleaning frequency is suggested to minimise the impact of scaling. Plant specific scaling rates may suggest higher or lower cleaning frequencies. Many of these meters are available with retractors and are designed for online insertion through a DN50 to DN80 valve to facilitate removal for cleaning.

During the Te Mihi expansion of the Wairakei Steamfield, vortex flow meters were trialed for use in brine service. The shedder bar quickly scaled, rendering it useless (Figure 2). These meters had to be retrofitted for ultrasonic meters (see Section 3). It should be noted that in this instance, the steamfield was run at a temperature closer to the silica saturation temperature for commissioning purposes for a period of time, leading to higher scaling rates. A steamfield with low brine scaling rates may see a better a success rate with vortex meters, though given the similar installation costs, ultrasonic flow meters have become the preferred solution.

Figure 2: Vortex shedder bar blocked with scale due to use in geothermal brine.

2.3. Calibration

Vortex flow meters rely on calibration factors which are related to the Strouhal number for a given shedder bar geometry as well as tuning factors for the vortex sensor. Unlike traditional restricted area differential pressure flow meters, which can be checked against reference pressures and dimensions, these calibration factors are often difficult to trace back to first principles without manufacturer specific knowledge. Hence vortex meters must be sent off-site to be calibrated against a known flow on a traceable flow bench.

If traceable flow measurement is required, such as for volumetric consent limits or emissions trading schemes, it is advisable to purchase a rotable spare to allow the meters to be sent off-site without causing major lapses in process measurement.

3. ULTRASONIC FLOW METERS

Commercially available ultrasonic flow meters comprise two technologies: Doppler shift and transit time. Doppler shift meters measure the frequency change in reflections of an ultrasonic signal off of entrained particles or air bubbles in the liquid. Transit time meters place an upstream and downstream transducer on the pipe wall and measure the elapsed time between the transmission and reception time of an ultrasonic signal. A pulse is sent and measured in both the upstream and downstream directions, and is slowed or accelerated as it travels with or against flow. These times, combined with the speed of sound in the fluid and a known distance between the transducers, can be used to calculate the average fluid velocity.

Transit time ultrasonic flow meters were selected for brine flow measurement. These meters are the type discussed in the remainder of this section. This choice is largely due to the availability of these types of meters for high temperature service, and not any concerns about Doppler technology being unsuitable for geothermal service.

3.1. General and Installation Concerns

There are two types of transducer installations, wetted transducers and clamp-on. With wetted transducers, the piezoelectric element is immersed in the process fluid, and with clamp-on type meters the transducer is placed on the pipe wall and transmits its pulse through the pipe into the fluid.

Portable clamp-on style transit time ultrasonic meters have been used for many years for testing purposes, though it was not until 2012 that ultrasonic flow was first used for permanent online flow measurement. Previous to this there were general concerns that these devices were not reliable enough for process measurement, as the clamp-on device had been difficult to set up and use on some brine lines. There were also concerns that the wetted transducers would quickly scale, rendering them useless.

Experience has shown otherwise, and as of this publication, the Wairakei and Ohaaki steamfields have seen three years of positive experience with these meters at seven different brine locations, four condensate locations and three oil locations. The brine locations are all wetted transducers, and the remaining locations are clamp-on.

Transit time ultrasonic meters lose their signal when the process fluid becomes aerated, so they should be installed in horizontal locations with a sufficient head of water and straight pipework to prevent the system from aerating or flashing. Conversely, the diagnostic features on many of these meters are good at showing that aeration is occurring (the signal strength drops to zero and the calculated sound speed is erratic). This can be useful for process diagnostics; for example at Te Mihi these meters have been used to show that air entrainment was occurring when foam formed in the cooling tower due to biocide dosing.

Ultrasonic meters are also available as spool pieces or as weld-in kits. The spool meters are easier to install, but are generally more expensive and have longer lead times, as they are usually made to order. The weld-in kits require transducer holders to be installed at precise locations and angles to align the transducers. Experienced fitters/welders with an attention to detail are necessary for measuring and marking pipe when using weld-in transducer holders. Practicing measuring and aligning the system on scrap pipe ahead of time is generally a good practice with new installers.

Some of the weld-in kits are available for hot tap online installations, though the authors of this paper do not yet have firsthand experience with the installation of these kits.

3.2. Scaling

Clamp-on meters have been used on relatively clean brine lines, and are able to measure flow through uniformly distributed scale of limited thickness (less than a few millimetres), such as scales found on higher temperature brines or on acid dosed systems. Thicker non-uniform deposits tend to disperse the ultrasonic signal as it passes from the pipe wall into the scale.

One of the locations where a wetted type meter has been installed was at the inlet to the Wairakei Binary Plant (a retrofit for a blocked averaging pitot tube), which has high scaling rates due to the lower process temperatures. This location has been operating with good results since November 2014, so limited experience suggests that wetted type transducers may be better suited to this application, although it should be noted that low temperature untreated brine is a difficult application for any type of meter.

One of the instrument manufacturers has made unsubstantiated claims that the ultrasonic pulses may actually help prevent scale from forming on the wetted transducers. This claim could be further studied using scaling coupons of identical dimensions installed in the same location, though no attempt has been made to do so.

As discussed above, it is advantageous to insulate the transducers to help prevent scale from forming (Figure 3).

Figure 3: Ultrasonic flow meter with removable insulation and cladding covering the transducers.

3.3. Calibration

While some ultrasonic manufacturers will advertise 1% or less accuracy of the measured value, this is for ideal conditions, and geothermal processes are far from ideal. Generally, the consensus is that these meters deliver approximately 2-5% accuracy, depending on the installation.

Calibration of wetted ultrasonic meters can be difficult. Spool piece meters must be removed and sent off-site for flow bench testing, which usually necessitates a system outage for removal and reinstallation. The weld-in type transducers may be removed in pairs and sent for calibration, though this would likely have to be done through the manufacturer. The only option for in-situ calibration is to cross check these meters with a known flow such as another calibrated clamp-on meter or tracer flow tests, though these measurements generally have similar error bands, making this more of a cross check than a true calibration (the general rule of thumb is that the reference measurement should have 10 times the accuracy of the device being checked).

Additionally, some of these meters are offered with RTDs or thermocouples to compensate for the fluid's sonic velocity (which is related to viscosity) and increase accuracy. As most geothermal systems run at relatively constant temperatures, this is generally not considered of enough benefit to warrant the additional complication and possible failure point.

4. NON-CONTACT RADAR LEVEL

There are two general types of radar level transmitters, non-contact and guided wave (which will be discussed in Section 5). Non-contact radar level transmitters are mounted above the vessel and bounce a signal off of the liquid or solid interface and measure the time it takes for the signal to return to the gauge. There are two types of these radar signals, pulse and frequency modulated continuous wave, though the measurement principle is similar for both.

These devices have been used successfully for measuring cooling tower basins, brine holding pond levels, and weir box flows (as many of these devices have built in linearizations for triangular and square notch weirs).

4.1. General and Installation Concerns

Non-contact radar devices are relatively easy to mount. They are available with flanged, threaded or bracketed connections. The mounting should be robust and stiff enough to prevent vibrations from affecting the measurement. For weir boxes they should be mounted upstream of the notch at a distance of 4 to 5 times the notch height. The radar device should be set at an appropriate height to keep it away from the hot brine and steam (1.5m above the surface is generally sufficient), but low enough to ensure that the radar beam is kept within the walls of the weir box (Figure 4).

Figure 3: Non-contact radar measuring weir flows. Note the remote display and removable bracket.

For servicing it is good practice to mount the transmitters in locations where they are safely accessible. When mounting these radar devices over a geothermal weir box, a gantry or removable brackets should be used so that the device can be removed and worked on away from the steam plumes which form above the weir box.

Many of these devices are optionally available with remote-mount displays so that the device can be set up and values can be read from a safe location (such as away from steam plumes or at the bottom of a tank).

4.2. Scaling

Non-contact radar does not touch the process fluid, so scaling is generally not a concern. These devices have been used to replace pressure transmitters on weir boxes, which frequently failed due to blocked tapping points.

4.3. Calibration

Radar level devices are relatively simple to calibrate, as they can be checked against a known distance.

When performing initial setup, tape measures, a surveyor’s dumpy level or a laser measuring system can be used to zero the device's installed height against the bottom of the vessel or weir notch. For weir boxes this measurement can be taken while the system is flowing but is best done with the system offline as process steam can make this measurement difficult.

These devices are generally accurate (~2-3mm). For weir box applications, these devices seem to produce a more stable measurement versus pressure/level transmitters, as the radar beam is spread across a wider area.

5. GUIDED WAVE RADAR LEVEL

Guided wave radar level transmitters function in a similar manner to non-contact radar devices, except that a rod extends to the bottom of the measured fluid to focus low energy microwave pulses. Some of each pulse is reflected and some continues down into the fluid, creating secondary reflections and allowing the measurement of liquid/liquid interfaces (such as oil/water) or foamy mixtures.

This ability to measure foamy interfaces is advantageous for geothermal brine level measurements, such as separator vessel or drain pot levels, where a bi-phase mixture might exist (Carroll et al., 2011).

Traditionally, float level switches (Mobrey™ switches) were used for water level alarms and trips (such as steam line water carryover detection). Since these float switches had moving parts in contact with geothermal fluid, they had to be regularly tested (bi-weekly for critical applications) to detect when switches had failed in place.

By replacing a switch with a level transmitter with no moving parts, reliability was increased and trends in level were able to be monitored. The first retrofit of guided wave radar devices occurred in January 2015 at Poihipi Station (Figure 4), with additional retrofits planned within the year at Wairakei Station.

Figure 4: A guided wave radar device being used to monitor drain pot level. Note the insulation on the level bridle and the remotely mounted transmitter.

As these devices tend to fail from process value to zero or to full scale, issues with the device are easier to detect. By replacing a switch with a transmitter, multiple alarm limits can be added without requiring multiple instruments.

5.1. General and Installation Concerns

Guided wave radar devices should be installed in level bridles with a minimum diameter of DN80, and off of tapping points with a minimum diameter of DN50 to prevent buildup from fouling the device. A blow-down valve should be provided at the bottom of the bridle to clear debris.

The device can also be supplied with disks which prevent the rod from vibrating and contacting the bridle wall; these disks should be matched to the size of the bridle.

5.2. Scaling

While these devices are generally more robust than mechanical switches, the guide rod is still prone to scaling, which can disrupt measurements. A monthly routine should be set up to blow down the bridle to clear scale and debris. Some of these meters also offer advanced diagnostic capabilities which can detect scaling.

Guided wave radar devices are not recommended for geothermal weir box applications as scale would rapidly build up on the guide rod.

5.3. Calibration

Similar to non-contact radar devices, guided wave radar devices can be calibrated versus known distances relatively easily. If the device cannot easily be removed online, a level column or calibration vessel should be provided to cross check the level transmitter.

6. CONCLUSION

By upgrading instrumentation in geothermal steamfields, it is possible to increase reliability, regulatory compliance and process safety. With careful selection of devices, following the general principles detailed in Section 1, many new instruments have been successfully installed and used.

ACKNOWLEDGEMENTS

The authors would like to thank Contact Energy for providing the time and resources to draft this paper, Kim Harwood for providing technical review, and Karin Horler for providing professional editing services.

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