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Real-Time Sensors for Multi-Phase Flows: Results of Field Trials and Further Study

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ABSTRACT

Field trial results of ongoing work on two new sensor techniques is presented. These two sensors provide real-time flow data for two-phase or multi-phase flows. Included are new field trial results and updates of calculations from previous trials.

1. INTRODUCTION

Determination of flow information in two-phase or multi-phase flows can be a challenge. Doing so in the high temperature chaotic flows that come from geothermal wells simply makes this more difficult. Methods for real-time flow data are available, such-as the use of two-phase orifice plates, but such installations are not universally used due to difficulties with scaling and the need for maintenance that can only be performed with the well off-line. Most facilities rely on methods that provide accepted results without the ability to provide this information real-time. Real-time data allows for better system planning, whether the need is for tune up of day-day operation or for larger factors such as load balancing and grid stabilization.

2. WHY THESE SENSORS, WHEN OTHER METHODS ARE AVAILABLE

Most current methods in use for two-phase flow measurement do not offer real-time results, yet have a long and successful history of use. Only recently has the need for real-time data become more important. Many worldwide geothermal resources have changed with use, some have shown decline, and others are now in strong financial competition with other types of renewable power sources. Base load operation of geothermal plants now requires more agility, with the ability to change output in a timely manner. The most common two phase flow measurement methods are tracer flow tests and horizontal discharge tests. Both methods are not real-time, therefore cannot offer the necessary data for analysis of flows on a day by day or hour by hour basis. Well response is measured quarterly, or in extreme cases monthly, which is still no more than one data point per month. With such data, there is no way to effectively track effects of one well on another. Alternate real-time measurement methods include the use of two-phase orifice plates. Such plates have gained some acceptance in U.S. facilities, but have not found the same level of use in other locations worldwide**.** The use of such plates will necessarily produce a pressure drop in the line, and a pressure differential at the plate itself, which may create issues with scale. Being internal to the pipe structure itself, maintenance of such plates requires a shutdown of the flow. Indeed installation of such plates must also be performed during a shutdown of the flow, as special orifice flanges with dual pressure taps must be added to the piping.

The two sensor methods discussed here are specifically developed to allow installation with minimal or no pipe modification. Their use does not affect pipe pressure, and any maintenance required can be performed without the need for shutdown of the flow. Both methods are based on the concept of 'minimal hardware installed, and maximum use of software analysis'. The data obtained is best described as a measurement of open air space in the pipe (void fraction), instead of an actual value of dryness fraction as previously reported.

3. FIELD TRIALS TO DATE

Detailed information about the sensor methods themselves can be found in the references, but it will be noted that more information can be found when more than one sensor is used at each well. With two sensors, a determination of flow velocity can be calculated. This can be used along with the void fraction information to determine mass flow of water in the system. The sensors have been field-tested in four separate locations in three different countries. In two of the installations, both sensor methods were able to be installed at the same time, whereas in the other two only the LC sensor was able to be deployed. Only a few of the test locations have allowed for two sensors of the same type to be used on one well at the same time. This has limited the amount of datasets available for software analysis and evaluation, and it is hoped that more test locations can be defined for sensor deployment.

4. SENSOR TYPES

There are two sensor types, the LC sensor, and the RF sensor. The LC sensor measures pipe content by evaluation of weight. The RF sensor measures pipe content by evaluation of internal pipe impedance. Both measure water content inside the pipe. Both offer data in real-time (per minute) intervals. The theoretical accuracy is +/- 2%. The two sensors use very different means to measure the pipe content, but can use similar software for data analysis. The LC sensor installs at pipe supports, with no contact to geothermal fluid, and takes advantage of the way most geothermal piping is installed on sliding pipe supports throughout the steam field (figure 1). The RF sensor installs through standard pipe tap ports, often readily available, to allow a probe to be injected into the pipe volume (figure 2). The RF sensor requires a pressure seal at the actual installed antenna, but is less affected by pipe stresses or environmental effects.

Figure 1: Pipes in steamfield on sliding pipe supports, and LC sensor installed at one such support.

Figure 2: RF sensor installed through standard TFT injection port, and second sensor installed at sample port.

5. FIELD TRIALS: DATA ANALYSIS

The sensor data is similar from both sensor types. Trends can be found in the data by statistical evaluations such as standard deviations, frequency analysis with Fourier transforms, pattern recognition, and time correlation. Raw data can appear like that seen in figure 3 below, however a weighted average allows specific events to be seen. Results of a weighted average are shown in figure 4.

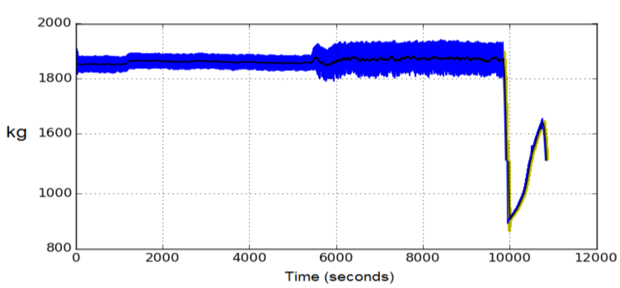

Figure 3: LC sensor raw data

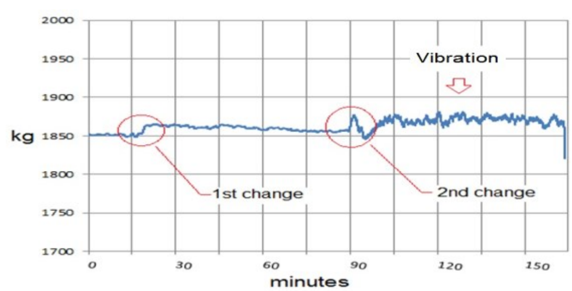

Figure 4: LC sensor date after analysis with weighted

The field results shown were taken during a horizontal discharge test. Three separate events can be seen, the initial flow before any valve changes, the first valve change, and then major vibration and variance after the second valve change.

5.1 Standard Deviation

The effects seen after the final valve change in the field trial above are more promounced when the results are analyzed with standard deviation, as is shown in figure 5.

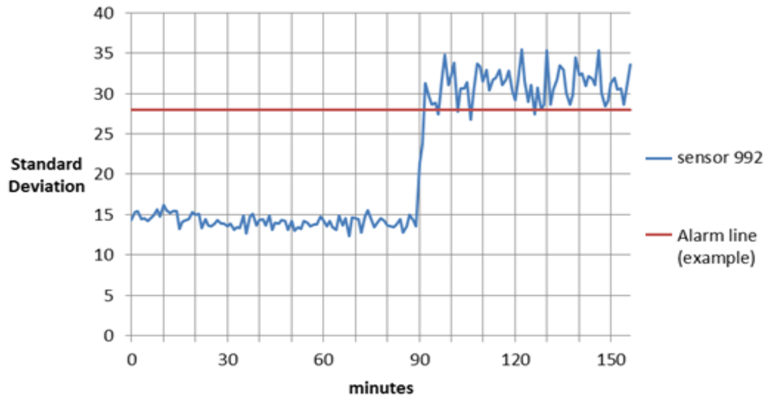

Figure 5: LC sensor date results analyzed with standard deviation

Comparison of standard deviation results to the intial raw data shows that the deviation did not change significantly during the transition that occurred from the first valve change. However the result is very pronounced after the second valve change,when the well was 'choked'. The test was stopped at this point, primarily due to the increase in vibration, which is also seen in the analyzed results. The analysis by standard deviation may be able to allow the sensor to serve as an alarm for such conditions.

5.1 Frequency Analysis

Sensor data appears random when seen in raw form, but there are other aspects of the data that can be discovered. The field trial results for the RF sensors have not shown any consistent periodic responses, but when using the LC sensor certain environmental effects may appear in the data such as pipe vibration. These can be found via Fourier transform and filtered from the dataset if necessary.

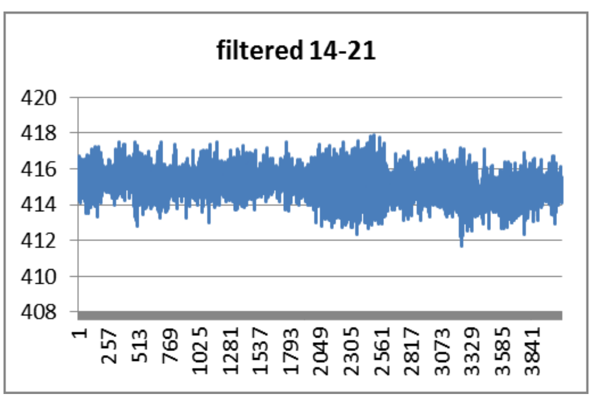

Figure 6: LC sensor data

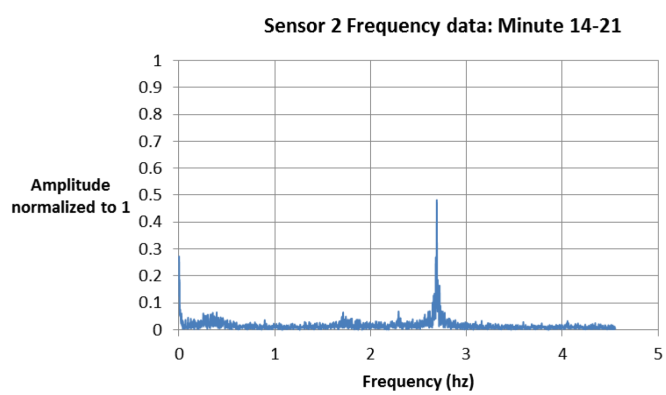

Figure 7: Fourier transform of LC sensor data

The specific frequency found in the sensor data (2.75hz frequency, figure 7) was found to be due to pipe vibrations between two locations on the pipe isolated by a fixed support. In this particular field trial the pipe was no longer resting on its sliding supports, and was held in the air by thermal expansion of the well itself. The pipes were floating off their sliding supports, and only anchored above-ground at the fixed support locations.

5.2 Pattern recognition and time correlation

When two sensors of the same type are used on the same well, the data collected from both can have similar response. Flows in the pipe vary naturally, and provide differences in water content that move down the pipe. With two sensors placed a distance apart along the pipe itself, the variable flow will pass by one sensor then the other, with such variances offset in time dependent on the distance between the two sensor locations. Finding this time offset can lead to a calculation of water flow velocity, and in turn to water volume flow rate, since the pipe internal volume is known.

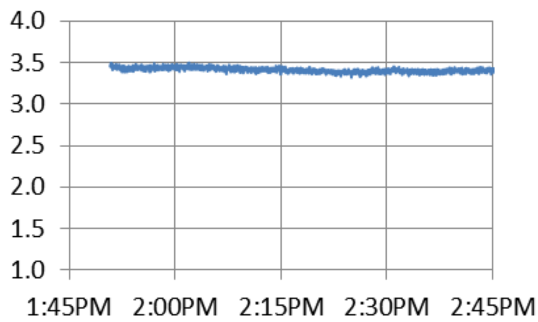

Figure 8: RF sensor 1 raw data

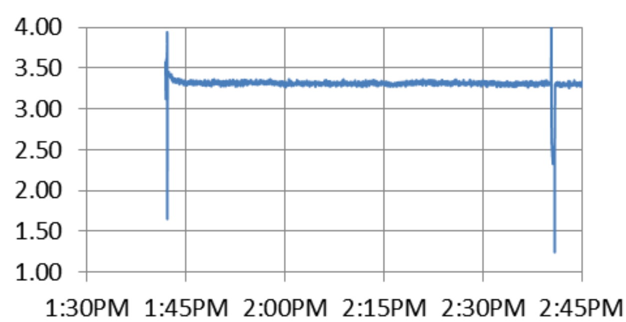

Figure 9: RF sensor 2 raw data

Time correlation is performed using results from both sensors and the velocity of water flow is calculated using the time offset. Using this velocity with the physical distance between the two sensors on the pipe, and the pipe internal cross section, a calculation of water mass flow can be performed. Figure 10 shows results of this calulation on the datasets seen in figures 8 and 9.

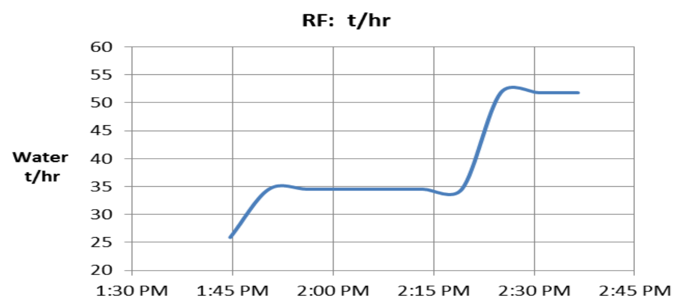

Figure 10: Water mass flow rate calculated with results from two RF sensors

6. CONCLUSION

Results have been presented that show two new sensor techniques for real-time tracking of two phase or multi phase flows. The sensors can track changes in water content in the flow. Both sensors are able to be installed and maintained in field piping while the well is in use.

Analysis of the data obtained shows that the sensors can readily track changes in the flow in real time, allowing the sensors to provide a signal or alarm of changing or dangerous flow conditions. The LC sensor in particular can also track vibrational events in the piping. If two sensors are used together on the same well, flow velocity information can also be determined, which can lead to calculations of water mass flow.

More capabilities can be found from real-time data, including determination of well interactions (when sensors are used to monitor multiple wells simultaneously), monitoring of performance when the facility undergoes changes such as load balancing, and detailed monitoring of flow regimes and flow direction.

The current field trials completed have provided datasets that are being used for software development, yet more data is required. The variety of the data obtained has shown that testing the sensors at real world wells and operational steamfields provides much more useful data than tests in the laboratory, and it is hoped that more field trials can be performed.

REFERENCES

Helbig, S., and Zarrouk, S. J.: Measuring two- phase flow in geothermal pipelines using sharp edge orifice plates. Geothermics, 44, 52-64. (2012).

Sisler, J., Zarrouk, S. J., Urgel, A., Lim, Y.W., Adams, R., Martin, S.: Measurement of two phase flows in geothermal pipelines using load-cells: Field trial results.
Proceedings, 41st Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, February 22-24, 2016 SGP-TR-209

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