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Design of a long term hydraulic fracture and flow system

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ABSTRACT: A series of fracture and flow tests are being performed at the Sanford Underground Research Facility (SURF) as part of the EGS Collab project. The tests involve generating a communicating fracture(s) between two boreholes, and monitoring flow through the generated fracture(s). To perform these tests a robust, remotely operable pressure system is required, as much of the flow testing will be performed over long periods of time when the equipment is not monitored. The system utilizes several pumping systems to include air driven liquid pumps, syringe pumps, and a triplex pump. The syringe pumps and triplex pump are connected to a data acquisition and control system, and can be controlled remotely for pressure and flow. The triplex pump is controlled using a variable frequency drive and a pneumatically actuated back pressure control valve on an integrated flow bypass line. A secondary back pressure control valve can be used to generate back pressure in the production side of the system. The injection and production test intervals are connected at the surface via high-pressure tubing and a differential pressure gauge, and downstream of the production well a series of sensors are in place for detecting tracers injected into the system. The pressurization system is connected to the in situ fracture through a pair (one in each of the boreholes) of straddle packers with a proprietary measurement tool in the packer interval. The tool, dubbed the SIMFIP (Step-Rate Injection Measurement for Fracture In Situ Properties) packs off and allows flow into and out of the interval along with collecting data from numerous sensors. Data from the shakedown of the system, performed at Sandia National Laboratories prior to field deployment, will be presented.

1. INTRODUCTION

The Engineered Geothermal Systems (EGS) Collab project is a multi-institution (comprised of national labs, universities and industry partners) Energy Efficiency and Renewable Energy (EERE) Department of Energy (DOE) project where research and development activities and testing in an underground facility (Sanford Underground Research Facility, SURF) are being used to increase our understanding of intermediate scale rock mass response to hydraulic stimulation and flow, thus increasing our understanding of the thermal-hydrological-mechanical-chemical response of the rock mass to engineered activity.

This effort is being undertaken as a primer project for the Frontier Observatory for Research in Geothermal Energy (FORGE) project, where the DOE is building a full scale EGS field site for ongoing research in EGS, which offer the potential for a tremendous renewable energy resource.

More detailed information on the EGS Collab project can be found on the DOE website under https://www.energy.gov/eere/geothermal/egs-collab

This paper documents the design and fabrication of the pressure systems used to perform the first field test at the SURF field site (Kneafsey et al., 2018).

2. BACKGROUND

The EGS Collab project is by no means the first time a field scale EGS test has been performed. The first proposed EGS site was undertaken in 1970 at Fenton Hill, NM by Los Alamos National Laboratory (Kelkar et al., 2016). Since then a number of studies have been undertaken. In general these studies followed one of three paths, first, injection of fluids at pressures above the minimum in situ stress, generating tensile fractures (e.g., MIT, 2007; Brown et al., 2013). Second, injection of fluids at moderate pressures to induce slip on preexisting faults and fractures (e.g., Dorbath et al., 2009; McClure and Horne, 2014; Cladouhos et al., 2016). Or third, injection of large quantities of cold water at low pressures to induce thermal fracturing (e.g., Bradford et al., 2016; Rutqvist et al., 2016). Each of these methods has met with mixed success.

Some of the barriers that have caused mixed success with many of the previous EGS projects include: an incomplete understanding of the techniques required to stimulate fractures under particular stress conditions; limited ability to isolate zones controlling flow paths, lack of science-based long-term reservoir sustainability and management resources; limited technology for generating effective zonal isolation at high temperatures; and inability to effectively monitor permeability enhancement at the reservoir scale. These barriers are difficult for any one industry operator to address due to the small scale of the current geothermal industry. Through the involvement of the DOE, National Laboratories, Industry, and University partners coming together in the EGS Collab project, we hope to address some of these barriers.

There has been extensive research into the means and methods to stimulate and sustain an EGS system, however, due to questions that remain open regarding anisotropy, heterogeneity, and fracture/fault system interconnectivity there is no standard method for developing an EGS reservoir (e.g., JASON report, 2014). This results in an increased risk of induced seismicity, and as a result potential loss of public support for EGS. Therefore, the EGS Collab project is performing tests to investigate stimulation, fluid-flow, and heat transfer processes at the scale of 10-20m. This scale allows for a relatively simple field deployment for performing experimental studies, while still being able to be monitored precisely, and modeled in its entirety without significant simplifying assumptions/scale up.

3. EXPERIMENT DESIGN

EGS Collab Experiment 1, which this system was designed for consists of a number of steps. First, after site selection, a series of boreholes for stimulation (1), production (1), and monitoring (6) were drilled according to preliminary modeling and examination of existing data (Morris et al., 2018). The entirety of the boreholes were cored for analysis and laboratory testing. Subsequently the boreholes were logged with wireline tools to determine the quality of the boreholes, and locate any open/flowing fractures.

Geophysical tools were then placed and grouted into the monitoring boreholes. These include distributed thermal sensors, continuous source seismic, and resistivity among others.

Once the geophysical monitoring equipment is in place, a hydraulic fracture test is performed for stress measurement, and to initiate the stimulation between the boreholes. Over a series of days where the pressure is cycled, the fracture is incrementally extended from the stimulation well to the production well. Once intersected, another packer is placed to capture the injected flow, which is then collected and analyzed. Collected water will be analyzed for tracers placed in the flow stream, as well as any inherent tracers that are released and transported by the flow system. A thermal breakthrough test will also be performed with the stimulation system.

4. SYSTEM DESIGN

4.1. Pumps

The stimulation and flow system was designed to be as versatile as possible, and therefore has 3 different pumping mechanisms. First is a continuous flow syringe pump system that is capable of generating 34 MPa and flow rates up to 400 mL/min. The second is an air driven liquid piston pump which is capable of producing 3.2 lpm at 69 MPa, and finally a Variable Frequency Drive triplex pump which is capable of producing 13.6 lpm at 48 MPa. Each of these systems has different benefits and disadvantages, and all have the potential to be deployed based on the needs of the test. For example, if the syringe pump does not inject water at a high enough rate or pressure in order to generate a fracture, then the air driven pump may be used. Alternatively for the long term flow test, if there is significant leak off due to permeability of the host, or interconnected fractures, the triplex pump may be used for its high flow rate.

4.2. Plumbing

The plumbing system is comprised primarily of high pressure taper seal stainless steel tubing. All wetted parts are either stainless steel, brass (triplex pump), polyamide (flexible high pressure lines) or Buna N rubber (drain lines). The plumbing was designed as a series of 4 primary “panels” which are used to control different aspects of the system and direct flow/pressure as required. An overview of the system is shown in Fig. 1. Panel 1 is shown in Fig 2, which is used to measure and control the injection pressure and flow. Flow into the system is measured with a low pressure magnetic flow meter, but a secondary high pressure positive displacement flowmeter also measures flow injected into the stimulation well. An air piloted back pressure control valve is used to regulate the pressure injected into the system.

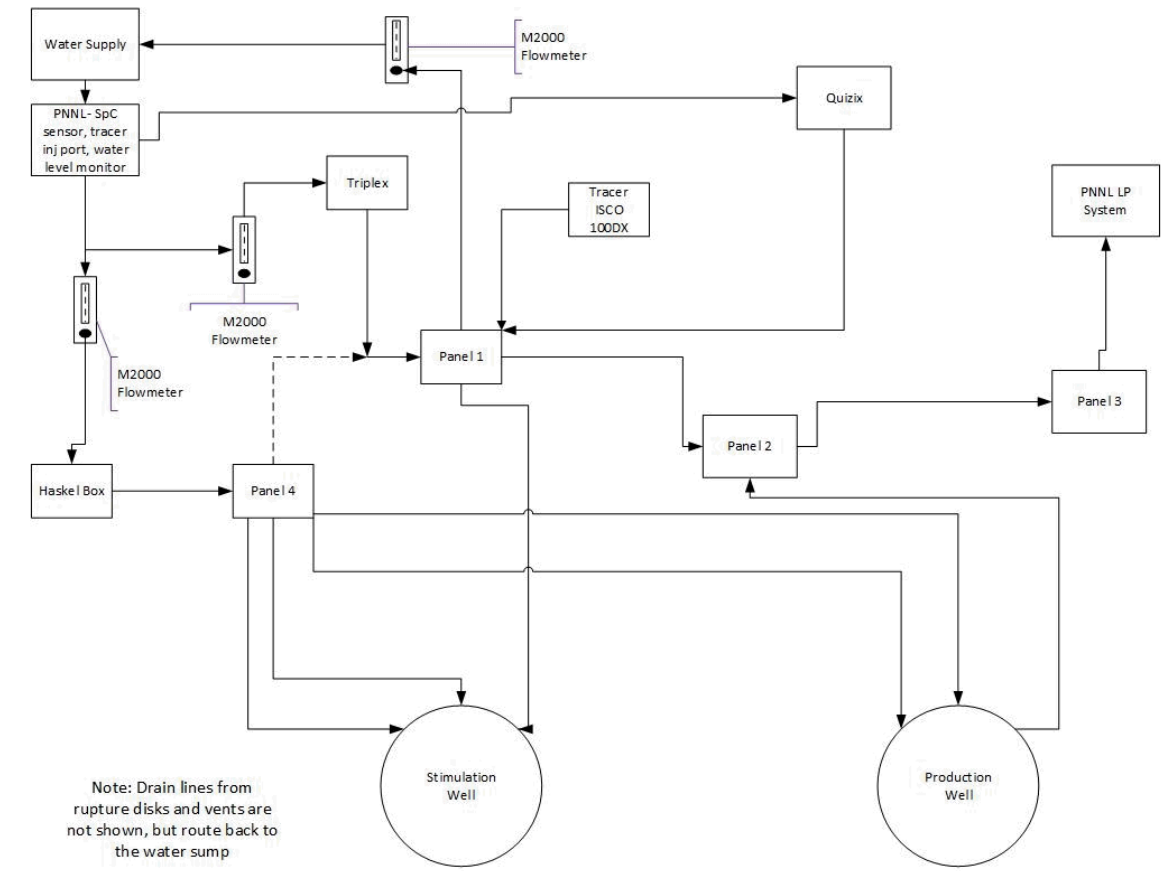

Fig. 1. Overview of pressure system.

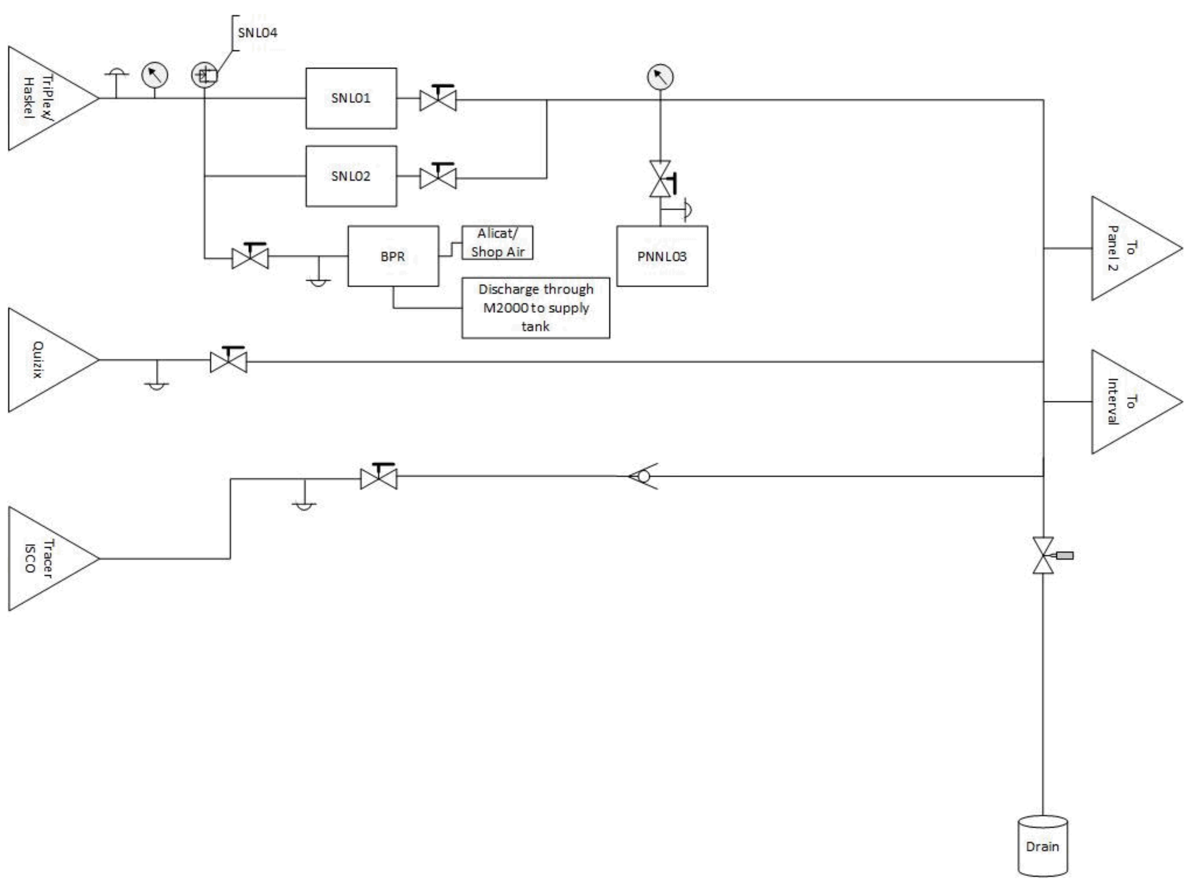

Fig. 2. Panel 1 diagram.

There is another low-pressure magnetic flow meter on the flow bypass line, and by subtracting that flow rate from the flow rate into the pump an independent measure of net injection flow for comparison with the high-pressure flow meter. This was done because the high-pressure positive displacement flow meters have a limited range over which they are accurate, which the magnetic meters do not. The positive displacement flow meters are also more susceptible to plugging. Tracer injection is also managed through this panel, via a separate injection line which connects to the main injection line. Tracers are injected into the line via a high pressure syringe pump (69MPa).

Panel 2 shown in Fig. 3 illustrates the design of the panel used to connect the stimulation and production wells. With this panel the pressures between the two wells can be equalized and differential pressure between the two can also be measured.

Panel 3, illustrated in Fig 4, is used to control back pressure on the production side through the use of an air-piloted backpressure control valve. There is also a filter in this system that is used to ensure that any sediment that may be transported up from the production well does not damage the backpressure control valve.

Panel 4, as seen in Fig 5 is used as a manifold to direct packer element pressures. The pumps mentioned in the previous section are also used to control packer pressure and pressure beneath the packers. Also, a continuous flow syringe pump system will be employed to maintain packer element pressure in the event of a small leak over long-term operation.

An example of one of the panels (Panel 2 in this case) is shown in Fig. 6. The panels are constructed of a steel and aluminum strut frame, and housed inside of an aluminum skin. This was done to provide rigid mounting for all of the plumbing, gages, and valves used in the system.

Downstream of the panels (after Panel 3) is a low pressure system which will be used to monitor the effluent water for tracers; the details of this system are not included in this paper.

4.3. Operations

Operation of the pumping system is controlled primarily by a LabVIEW implemented data acquisition and control system, developed at Pacific Northwest National Laboratory, which allows for control of the syringe and triplex pumps, as well as the back-pressure control valves. Therefore, once a flow regime is established the system can run autonomously through the use of PID control loops built into the control software. The system can also be remotely monitored and controlled while in this mode if changes are necessary while in long-term operation. The air-driven pump requires manual operation, to apply significant changes in terms of flow, or flow routing as it requires actuation of manual valves. Collection of tracer samples is achieved on a separate

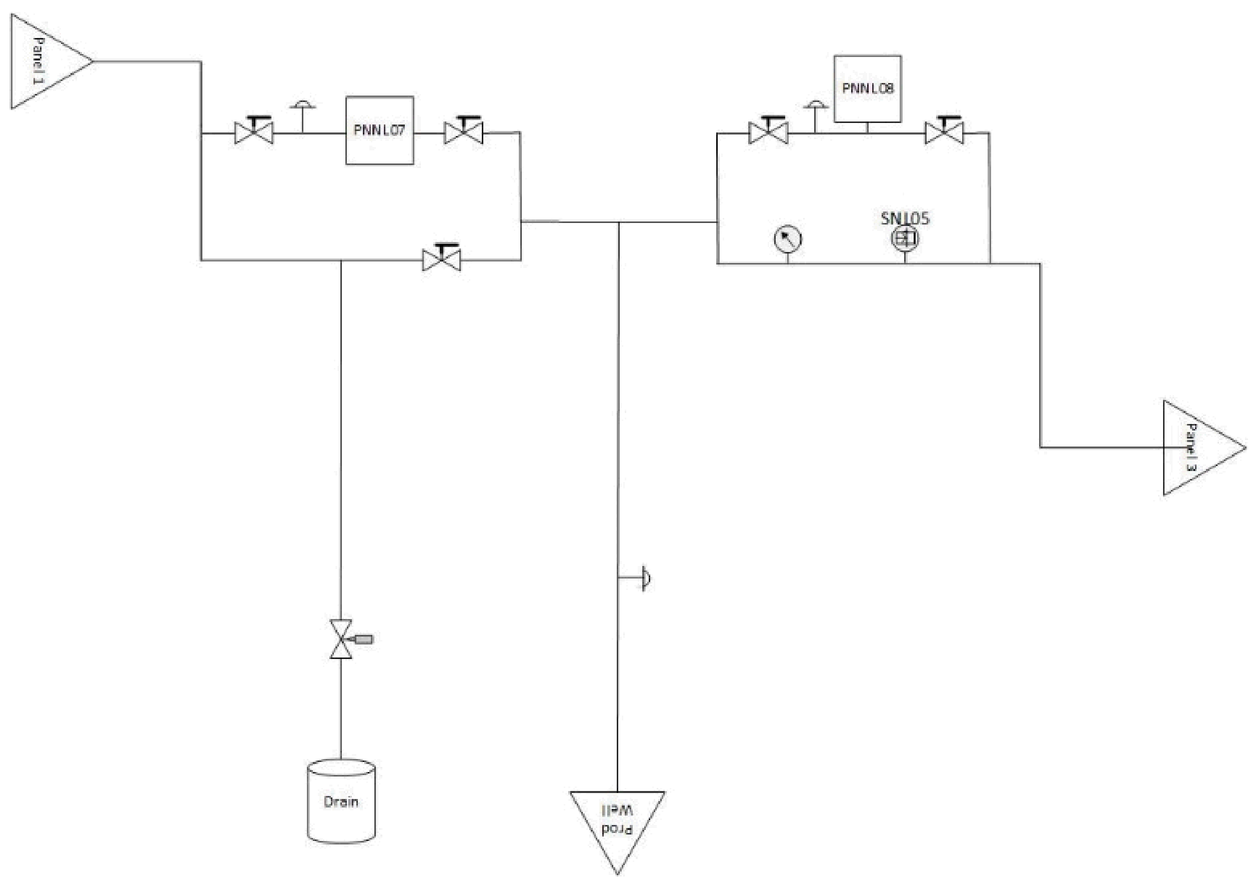

Fig. 3. Panel 2 diagram.

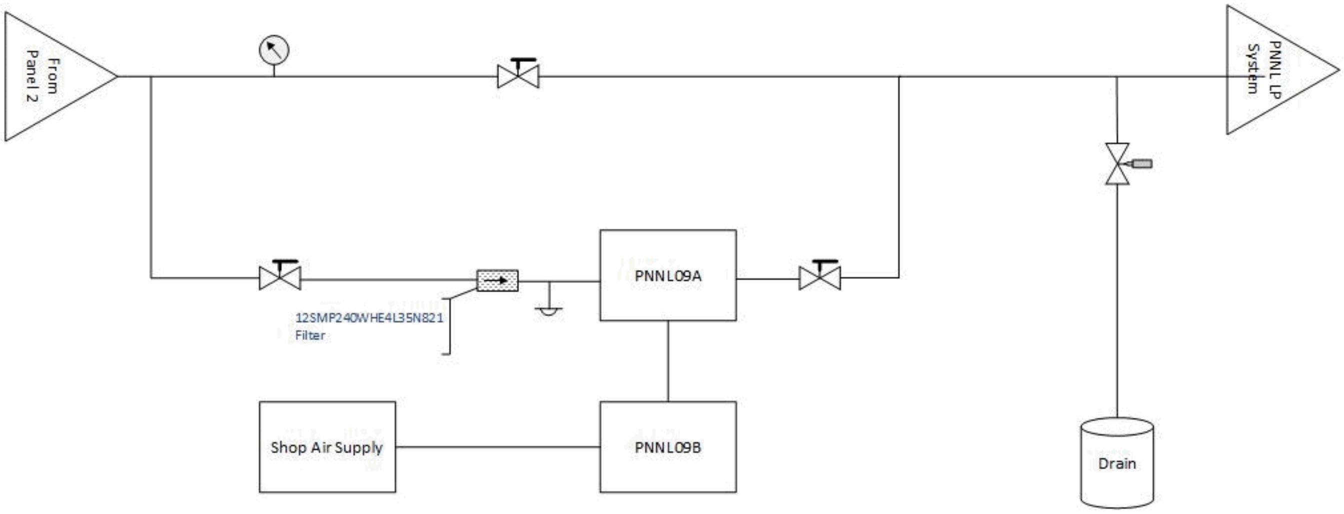

Fig. 4. Panel 3 diagram.

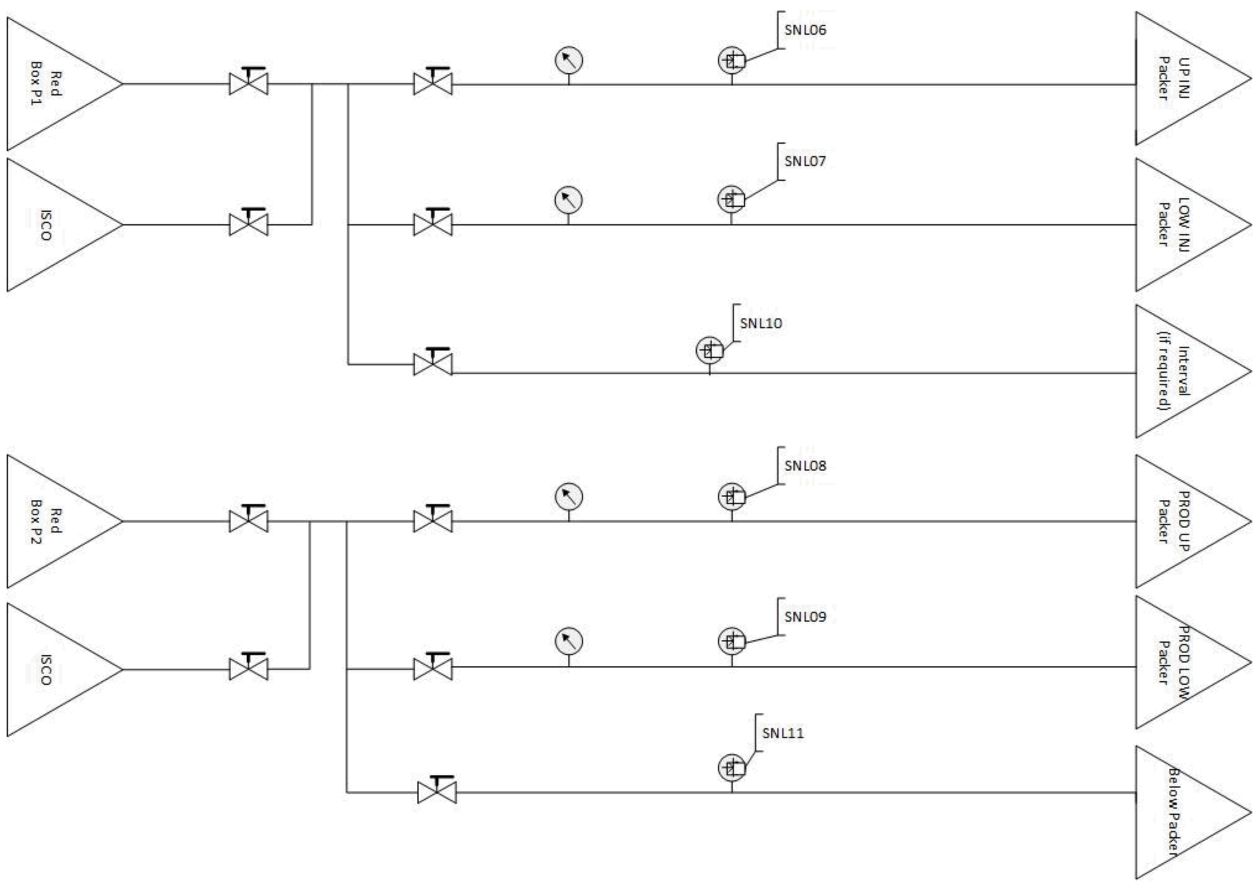

Fig. 5. Panel 4 diagram.

system. The data collection from the varied pressure transducers and flow meters is synced with a master timing signal generated by dedicated clock server. This signal is used to synchronize all of the data collection streams that are recorded in the project.

5. SHAKEDOWN RESULTS

A shakedown test of the system was performed at Sandia National Laboratories prior to deployment of the system to the field site. Some of the results of this shakedown are shown in Fig 7. This figure shows the results from the different flow meters that were employed in the operation of the system. Pressure data are not shown because the majority of the shakedown data were taken when the system was being held at a constant pressure. In this example the triplex pump was being used to generate flow at its minimum speed, but the desired flowrate was below that of the pump minimum. To achieve the desired flowrates more water was allowed through the bypass line using the backpressure control valve. The "pump in flow" indicates a relatively steady pump inlet flow (light blue line). The fluid moving through the bypass line is shown in orange and the difference between these two which is the calculated injection flow rate, is shown in green. The noisy blue line shows the data from the high-pressure positive displacement flow meter which agrees quite well with the calculated flow. Note that at low flows the high-pressure meter cuts out, illustrating the necessity for the low-pressure meters to capture the lower flows.

Fig. 6. Image of completed Panel 2.

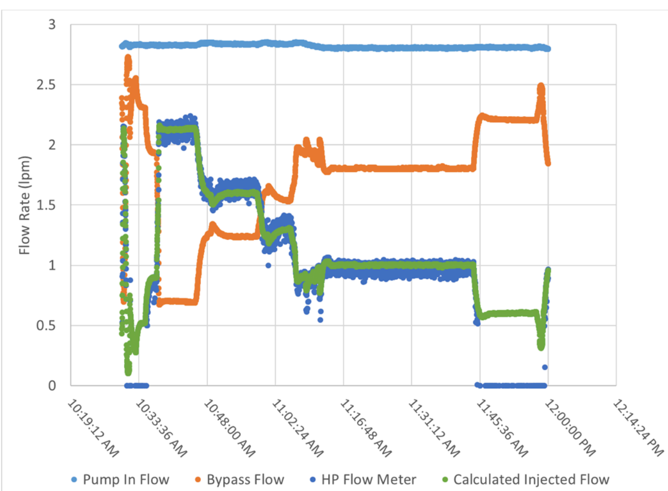

Fig. 7. Flow results from shakedown test.

6. CONCLUSIONS

This paper describes a flow system that we designed for the EGS Collab project. The pressure and flow system is highly configurable so that a relatively large range of injection pressures and flow conditions can be implemented. The system contains a number of pressure and flow sensors to measure both injected and produced flow from the system, and it is capable of controlling both injection and production pressure and flow at a high level of accuracy, as evidenced by the data collected during the test shakedown.

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