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**Federal Railroad
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Geothermal Switch Heater Installation, Testing and Monitoring – Phases 1 & 2

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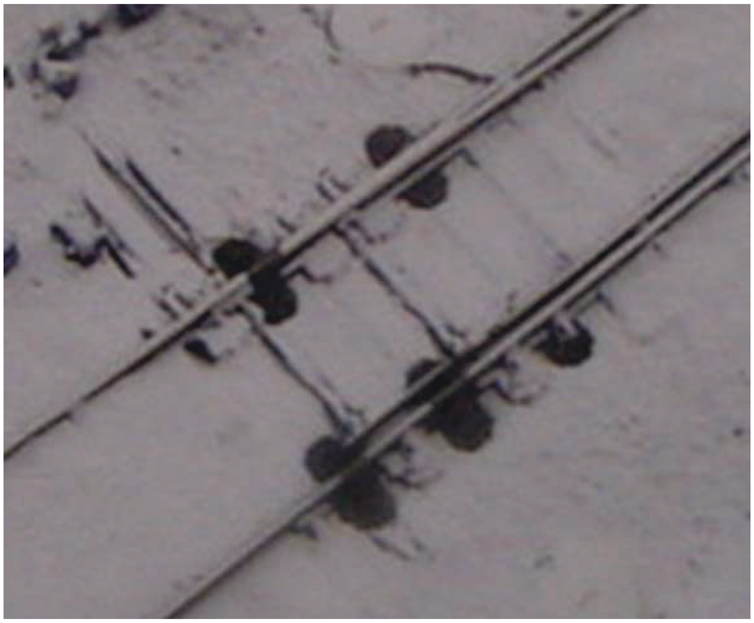
Development,
and Technology
Washington, DC 20590



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13. ABSTRACT (Maximum 200 words)

Transportation Technology Center, Inc. (TTCI), Norfolk Southern (NS), and John A. Volpe National Transportation Systems Center (Volpe) completed Phases 1 and 2 of a project on a working prototype geothermal switch heating system designed to test the concept and efficiency of using low-temperature geothermal energy (55°F) to heat a railroad switch plate. Research results indicate that geothermal switch heating technology is a viable alternative to traditional active heating systems for keeping track switches free of ice and snow in winter. Future work would be aimed at improving heat source, changing the tubing or switchplate design, using a geothermal pit instead of a well, and streamlining the assembly and installation process.

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1 cup (c)	=	0.24 liter (l)	1 liter (l)	=	0.26 gallon (gal)
1 pint (pt)	=	0.47 liter (l)			
1 quart (qt)	=	0.96 liter (l)			
1 gallon (gal)	=	3.8 liters (l)			
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)	1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)	1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)
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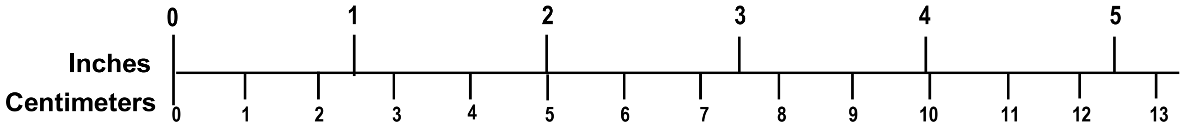

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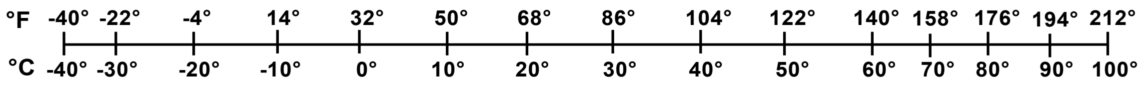

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- The FRA and Luis Maal for reviewing plans and developments
- Innovation und Verkehrstechnik and Wolfgang Feldmann as the technology inventor, for project input and ideas
- Norfolk Southern and Brad Kerchof, for project coordination, workplan and reporting review, site involvement, and personnel and equipment donation
- Volpe Center and Dr. Robert Wilson for reviews, comments, and site monitoring

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Illustrations

Executive Summary

Transportation Technology Center, Inc. (TTCI), Norfolk Southern (NS), and John A. Volpe National Transportation Systems Center (Volpe) completed Phases 1 and 2 of a project on a working prototype geothermal switch heating system designed to test the concept and efficiency of using low-temperature geothermal heat (55° F) to heat railroad switch plates. The Federal Railroad Administration (FRA) Office of Research and Development and Canadian Pacific Railway (CP) provided the research funding for this project.

The results of this research initiative indicate that geothermal switch heating technology is a viable alternative to traditional active heating systems for keeping track switches free of ice and snow. Additional developments are necessary to reduce installation and system costs, and to improve component design to a more efficient state. Specific recommendations include heat source improvements, tubing vapor lock design improvements, switch plate design changes, and analyzing the use of carbon dioxide versus ammonia for the working fluid by using the present study as a benchmark.

The technology takes advantage of higher temperatures underground by passively transporting thermal energy to the surface to heat the track switch to keep ice and snow melted in the switch. Liquid anhydrous ammonia, under pressure, transforms from liquid to gas within a borehole probe as it absorbs heat from the earth. The lighter gas rises up through the probe to ground level, where it flows through ground-level piping to the switch plates. The plates have a series of passages machined just beneath the surface that absorb the heat of the warmer gas as it condenses back to a liquid and flows back through the down-hole.

Phase 1 work installed a partially completed prototype system in September 2014, in the NS mainline at milepost (MP) 182.6, at the east end of the 55th Street Yard in Cleveland, Ohio.

Phase 2 involved addressing technical problems that were encountered in Phase 1 and installing a second system on the opposite side of the track to the Phase 1 system. The performance of the systems was monitored from February to spring 2015.

1. Project Background and Phase 1 Introduction

1.1 Geological and Hydrogeological Setting

Installation of a prototype geothermal switch heating system was performed at the Norfolk Southern main line, at MP B 182.6 near the company's 55th Street Yard Engineering Headquarters. Preliminary geological and hydrogeological work provided a basis for heat exchange estimates needed for the system to function properly (Figures 1 and 2).

The regional geology consists of Mississippian deposits of silt stones, shales of the Cuyahoga Formation, deltaic sandstones of the Berea Formation, and the silty shales of the Cuyahoga Formation, which are underlain by the Cleveland shales (Figure 3). These are the targeted formations for this geothermal heating system.

Throughout the Cleveland area, many of the glacial sediments and some rock layers carry water (*Encyclopedia of Cleveland History*), but are of limited extent and discontinuous. Groundwater is a desired and effective, but not required, condition for geothermal switch heating placement and use.

Figure 1. Test Location at 4790 Crayton Avenue, Cleveland, OH

Figure 2. Sporadic Glacial and Lacustrine Sand/Silt Lenses

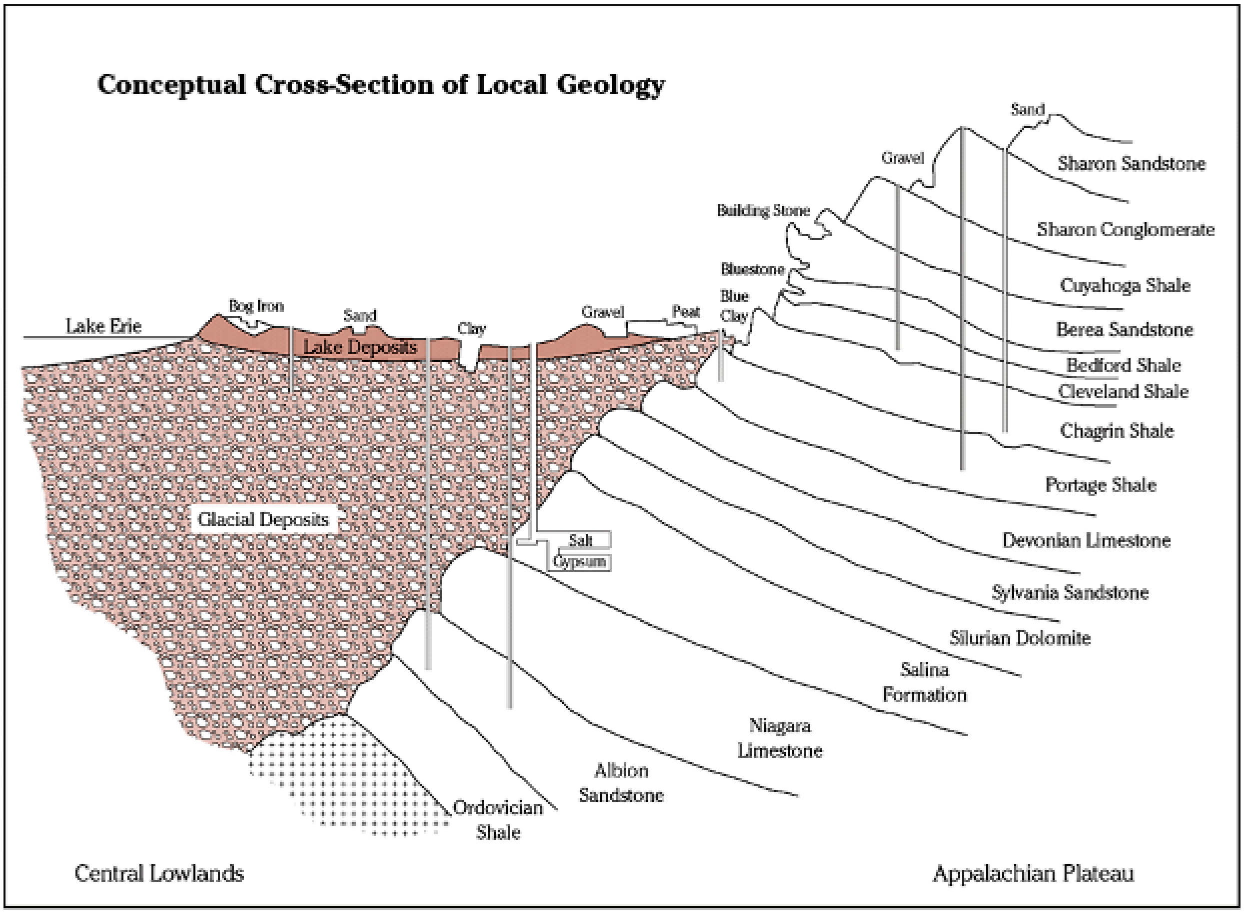


Figure 3. Conceptual Geologic Cross Section of Local Cleveland Geology

(*Encyclopedia of Cleveland History* source)

1.1.1 Preliminary Offsite Preparatory Work

Preparatory work necessary before project initiation included the following operations and tasks:

1. Geothermal Switch Heating System design – conceptual theory and initial drawings for the ammonia (NH_3) refrigeration system was provided by Innovation und Verkehrstechnik in Germany
2. Switch plate design and fabrication – by voestalpine Nortrak Inc.
3. Down-hole tubing design and fabrication – by Innovation und Verkehrstechnik and by Waterway Engineering, Germany
4. Instrumentation design and procurement, and project management – by Transportation Technology Center, Inc. (TTCI)
5. Research funding by the Federal Railroad Administration (FRA) and by Canadian Pacific Railway (CP)
6. Research site location and site coordination – by Norfolk Southern Railways (NS)

1.2 Organization of the Report

Section 1 gives introductory information regarding the geothermal switch heater installation and testing performed. Section 2 describes five tasks of the system installation at the NS site in September 2014. Section 3 describes the logging, monitoring, and telemetry systems installed as part of the test. Section 4 covers the ice test conducted on the partially completed system, and Section 5 details the steps forward and work plan to finish installation of the geothermal system.

1.3 Objectives (Phase 1)

Passive geothermal switch heating using refrigerant ammonia is being tested at a NS switchyard in Ohio, for effectiveness, efficiency, and economic benefit.

1.4 Overall Approach (Phase 1)

This cooperative research program consisted of locating and preparing the research site, design and construction of components, instrumentation, installation and initial testing of the switch heater system, and monitoring of the initial system operations.

1.5 Scope (Phase 1)

Two wells were to be drilled, one on each side of the switch, heat exchange tubing was to be installed down-hole; topside condensation plates were to be installed within the switch plates, and the system was to be monitored for one winter season (4 months). Ambient, track, switch, and down-hole temperatures were to be recorded at multiple points, and the system pressure was to be monitored.

2. System Installation (Phase 1)

2.1 Tie Plate Installation (Task 1)

Voestalpine Nortrak tie plates were installed in the switch during the week of August 31–September 6, 2014. The old switch plates were removed and 10 specially designed tie plates were installed before initiation of other system installations. The tie plates were designed for a left hand turnout that switches from the right side, which was the configuration at a previous location choice. The 55th Street location has a left hand turnout with switch stand on the left side, whose different layout was successfully accommodated by the switch plate installation gang during preliminary site activities. However, there were some problems matching the tubing to the switch plates as a result of the different head block configurations. Figure 4 shows the switch configuration and tie plate layout. The left graphic is Nortrac's left hand turnout design showing the switch head blocks on the right and the right graphic shows the left hand turnout installed at the test site.

Figure 4. Switch Configuration and Tie Plate Layout

Lessons Learned

Each turnout (right or left hand) and head block positioning may be different and may need a different plate design. This needs to be verified in the field before installation.

2.2 Drilling (Task 2)

Fronz Drilling drilled two boreholes to 175 feet according to the work plan, using a sonic drill rig. Continuous coring methods were used, producing a 4-inch diameter core in unconsolidated soils to 150 feet below ground level, and a 2-inch core in consolidated sediments from 150 to 175 feet below ground level. Golder Associates logged the boreholes and produced a drilling log of the results. Geothermal wells were drilled in predetermined locations; one on either side of the track. Figure 5 shows the sonic drill rig in operation and a 4-inch diameter sample extraction of soil.

Figure 5. Drilling and Sampling Well 1

The sonic drill rig used a high frequency axial vibratory load on the bit and drill stem, combined with water circulation to remove cuttings, to advance the drill string. Although the advancement of each 10-foot length of steel was fast (usually around 30 to 60 seconds), the sampling process was slow because the entire length of drill steel had to be removed from the hole in order to retrieve one 10-foot length of sample core, then it was re-inserted for the next coring interval (this process is called a “trip”). Thus, trip time increased with increasing depth.

Surficial soils were initially penetrated with a large diameter (12-inch) bit and surface casing during the setup phase of the drilling operation. The purpose of the surface casing is to provide a stable platform for drilling and to provide a conduit for drilling fluids to exit the borehole without washing out surficial soils. Drill cuttings and cores were logged by Golder Associates and were assessed in the field for engineering and hydraulic characteristics such as grain size, moisture content, stiffness, classification, and sample depth. This was followed by a 5-inch diameter soil coring bit that obtained the 4-inch diameter soil samples. Then the 2-inch diameter rock sampling bit was used to obtain 2-inch diameter rock samples. Figure 6 shows a 4-inch coring bit with carbide buttons and a borehole sample taken 30–40 feet below ground level, which contained very stiff, moist silt.

Figure 6. Coring and Sampling Well 1
(left) 4-inch Coring Bit and (right) Borehole Sample at 30–40 feet below ground level

After drilling the well to 175 feet below ground level, the sampling and coring steel was removed and the hole was reamed out with an 8-inch diameter bit to prepare the hole to receive the 6-inch diameter PVC well casing. The bottom 5 feet of the 6-inch well casing was slotted with 0.010-inch width factory slots. Solid casing was placed upward to a depth of 30 feet below ground level. Then 15 feet of 0.010-inch slot casing was placed from 30 feet to 15 feet below ground level to provide hydraulic conductivity between the perched aquifer and the borehole. The upper 15 feet of the well bore had solid casing, which excluded some of the surficial contaminated water noted during drilling. Since the formation below a depth of 33 feet is extremely tight and impermeable, the dissolved contamination would not pose a contamination threat to production aquifers located in the region.

The 6-inch casing was placed in the well and 8-16 (mesh size) sand was placed around the annulus of the casing to provide stability for the casing and to provide hydraulic (and thermal) conductivity to the refrigeration tubing that was to be placed in the well. The annulus sand was placed from the borehole base to a depth of 5 feet below ground level. The casing was cut at a depth of 3 feet below ground level to facilitate the placement of the instrumentation vault. Figure 7 shows the completed borehole at Well 1. The casing riser was cut off before the tubing was installed.

Well 2 was drilled with similar methods, except that it was not required to produce any soil samples. Consequently, Well 2 was drilled with the 8-inch diameter bit to the total depth, and completed in a similar manner as Well 1. Well 2 took approximately two days to drill and complete, compared to four and a half days for the first well.

Figure 7. Bore Hole 1 Completed
(casing riser was cut off before tubing installed)

Lessons Learned

The drilling operations required a total of approximately six days to complete, which was substantially more than the 2 to 2.5 days which were allocated. Although actual drilling time was minimal (1 to 2 minutes for 20 feet in unconsolidated soils) "tripping" in and out to retrieve soil and rock samples took an increasing amount of time as the boring was advanced down-hole. If the technology were to be used on a large-scale basis, it is not anticipated that coring and sampling would be necessary in every well, and different drilling methods may be used that could reduce drilling time.

A geotechnical investigation would assist the system design team in reducing unnecessary resource expenditures by targeting desirable hydrogeological environments. Another design could also be explored using a lined trench or pit filled with sand or gravel into which the tubing is inserted. This may require the use of a low volume solar powered fluid pump to drive the condensate to the extant area of the trench.

The potential issue of aquifer contamination must be considered when any drilling program is considered. Usable aquifers in the United States are strictly controlled and protected to maintain their utility as a water source, and any surficial contamination that could be introduced into underlying aquifers must be carefully isolated. A work plan must be developed that will assure that this legislative mandate is adhered to, and it must be approved by state authorities before a well is drilled.

2.2.1 Drilling Fluids and Waste Materials

Drilling fluids such as water and "drilling mud" were removed from the active area by Fronz Drilling during the drilling process and disposed of in a low use peripheral area. In a large scale installation operation, each switch area would need to be assessed for suitability to discharge fluids and cuttings onsite. Permits may need to be obtained in order to do this in some areas. In switch areas where soil or water contamination is present, care must be taken in the well design to prohibit the spread of the contamination to underlying production aquifers, which would have serious environmental consequences.

2.2.2 Subsurface Geology and Hydrogeology

Surficial soils consisted of angular ballast particles up to 2.5 inches in diameter to a depth of approximately 36 inches, in a dark brown, moist to saturated, fine grained sandy silt matrix. Ballast particles offered grain to grain contact, which produced a stable, drivable area. Groundwater was encountered at approximately 3 feet below ground level.

From 3 feet to approximately 15 feet, subsurface soils consisted of dark to medium brown, coarse to medium grained sand with silt that was saturated. A distinct odor of fuel or solvent was apparent in this zone, although no floating product or sheen was apparent on the water surface.

Fuel odor was not noticeable in the saturated silty sand encountered from approximately 15 to 33 feet, so this was the zone targeted with slotted casing during well completion.

Lessons Learned

Geology and hydrogeology of each site is an essential part of the project and is necessary for system design, but sampling during drilling is tedious and requires excessive track time. Online or library accessed preliminary data, preliminary site work, and a modified exploration program can eliminate the need for coring soil samples during onsite drilling activities. Site exploration options before a system is designed may include rail or truck mounted piezocone data collection, cone penetration test (CPT) exploration, or noninvasive geophysical exploration techniques.

2.3 Tubing Installation (Task 3)

2.3.1 Tubing Layout

Well 1 onsite tubing preparation began by laying 8 tubing pieces parallel to the track on several lengths of polyethylene plastic sheeting to protect it (Figure 8 (left). Tubing preparation continued by inserting tubing pieces through the stainless steel well cap, placing and securing the PVC spacer rings to the tubing with zip ties, placing the black foam stop on the tubing bundle, epoxying the tubing bundle into the steel ballast bottom weight, tying the pull rope onto the ballast weight, and epoxying thermocouples onto the tubing at 20-foot intervals. Figure 8 (right) shows the tubing array in the well cap and pull rope attached.

Figure 8. Tubing Layout and Assembly

Four pieces of the tubing were damaged by contact with a backhoe onsite during site activities. However, pressure and vacuum testing of the damaged tubing revealed no leaks, so the project proceeded as planned.

Lessons Learned

Future system planning should have a contingency for damaged piping, possibly using an engineering union or cap that can be silver soldered or epoxied onto the tubing string. Another option would be to have extra tubing available onsite that can replace any damaged tubes.

2.3.2 Installation of Spacers and Zip Ties

Spacers and zip ties were initially used to hold tubing apart down-hole, maximize tubing contact with groundwater. The cluster was to be 5-inch diameter, and the 6-inch PVC inside diameter was 5.5 inches, resulting in a clearance of ½ inch between the tubing cluster and the well inner diameter. It was found during tubing insertion that this did not allow enough room for sidewall frictional forces, buoyancy effects, and zip tie thickness. Figure 9 shows the tubing with the spacers attached and epoxying the tubing into the 85-pound steel ballast weight.

Figure 9. Tubing Preparation
(left) tubing with spacers (right) epoxying the tubing

2.3.3 Thermocouple Placement

Nine thermocouples were placed at 20-foot spacing along the length of the tubing to monitor down-hole temperatures under operating conditions. The first thermocouple was placed near the wellhead cap, and thermocouple wiring was routed through the wellhead cap center hole, with the pull rope.

2.3.4 Epoxying the Tubing into the Ballast Weight Tubing Cup

A ½ inch diameter polypropylene pull rope was tied into a welded ring down inside the ballast weight epoxy cup before epoxy placement. Then, the tubing was placed into the cup. The cup was then filled with approximately 24 ounces of fast cure liquid epoxy, so the tubing and pull rope were secured in the epoxy. A 10 percent excess of hardener was used in the mixture to expedite the curing process.

2.3.5 Tubing Placement into Well

The total length of the tubing was 160 feet plus 2 feet for the ballast weights, and the total depth of the well was 175 feet. Since the top of the tubing was placed at a depth of 3 feet below ground level, there was approximately 10 feet of open hole below the bottom of the tubing to accommodate possible lengthening of the corrugated tubing under pressure, down-hole silting, and other factors. The tubing was supported as it was lowered into the well, using a modified padded roller supported by a cable attached to the backhoe excavator arm.

Figure 10 shows the initial unsuccessful attempt at placing the tubing in the well, because the tubing was only able to be inserted to a depth of 110 feet below ground level. The combination of large (5-inch) diameter spacer rings, buoyant forces, and sidewall frictional forces from the zip ties on the spacers made complete insertion impossible with the available manpower. Ballast weight for Well 1 was 85 pounds, but should have been approximately 105 pounds.

Figure 10. Tubing Placement into Well 1 (first attempt)
(Note the 5-inch diameter white spacers)

The tubing was then removed, laid back out on the plastic sheeting, and the spacers were removed. The tubing was then configured into a smaller radius bundle and re-inserted into the well (Figure 11 (left). The second attempt was successful. Figure 11 (right) shows the well cap being tightened onto the well casing.

Figure 11. Insertion of Tubing into Well 1 (second successful attempt)

Lessons Learned

The assembly of the tubing string, ballast, and pull rope should be done before initiation of site activities, in a controlled (e.g. warehouse) environment. This would eliminate onsite assembly variables including potential for damage or accidents due to weather, equipment, site layout variances, etc. The finished tubing cluster could be spooled onto a reel on a winch truck and delivered to the site, ready for insertion as soon as it arrives.

The tubing string must have adequate ballast weight during insertion to keep it in tension, which means an excess of at least 10 pounds over the buoyant forces must be planned for the steel ballast weight. For this application, the weight for Well 1 should have been approximately 105 pounds instead of 85 pounds, and for Well 2 (which has fewer tubes) the weight should have been approximately 70 pounds instead of 55 pounds. An adequate knowledge of the subsurface hydrogeology is required to predict final groundwater level, well depth, and tubing length. In addition, tubing string must have at least 1-inch of free space between the largest diameter of the down-hole bundle and the casing inner diameter. An offsite assembly of the tubing clusters, knowledge of water table elevation details, an effective cluster design, and automated insertion techniques, could have reduced the onsite tubing preparation and insertion time from three days to 1 ½ hours or less.

2.4 Attach Down-Hole Tubing to Crossover Tubing (Task 4)

The Nortrak condensation switch plates were in place and ready to go before the system installation began on September 8, 2014. After the tubing was placed in the well, the crossover tubing was ready to be attached and the refrigeration tubing charged with ammonia.

2.4.1 Crossover Tubing Layout

Each of the switch plate condensation plates has a separate tubing set routed to it (Figure 12), so there are 10 sets of tubing for each side of the switch, passing from the wellhead to each plate. These tubes rely on gravity flow alone to move condensation fluid down-hole to be heated, so it is critical that they maintain proper slope towards the wells at all times.

The well vaults were placed over the wellhead and wellhead tubing cluster, in addition to the pull rope and topside thermocouple leads (Figure 13). Although the well vaults were 30 inches in diameter, rigid insulation placed on the inside of the vaults reduced the effective inside diameter to 28 inches, which proved to be a tight working space. The refrigeration contractor began the installation of the crossover tubing, but found that the threads on the valve bodies, nipple ends, flexible tubing, and refrigeration tubing ends had all been damaged (Figure 14). It appears that the threads did not match on the pieces, and were damaged during assembly. The contractor was able to salvage two of the tubing sets to provide a “proof of concept” test, but all tubing sets will need to be repaired before a meaningful test can be accomplished.

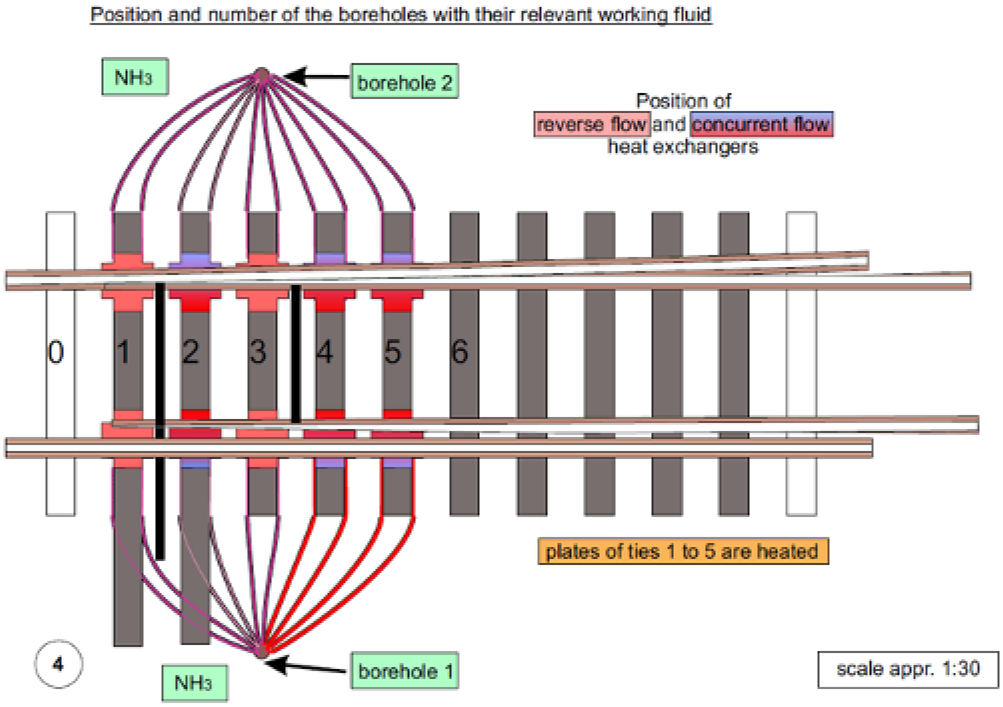


Figure 12. Switch Plate and Well Tubing Layout

Figure 13. Instrumentation Vault

Figure 14. Damaged Tubing Ends

Lessons Learned

NPT threads may look similar to ISO 7/1 threads; however, ISO and NPT threads should not be mixed, since ISO threads have a 55-degree taper angle versus 60-degree taper angle for NPT threads. In addition, stainless steel cannot accommodate any thread deviations without galling. Other pipe threads that may cause confusion are shown in Figure 15. Each type has a different application, time era when they were used, or use in a geographical region. Reference 2 is one pipe manufacturer's white paper on different types of pipe threads.

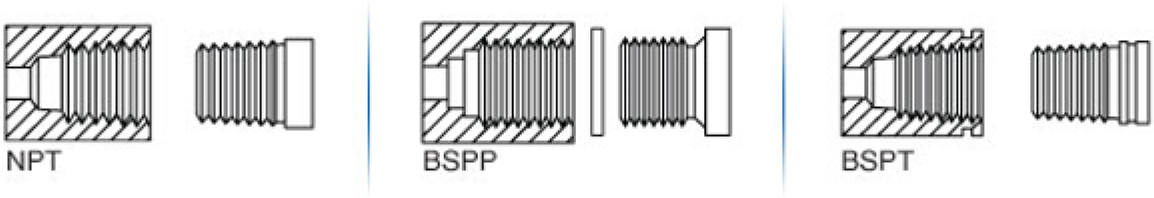


Figure 15. Pipe Threads (left) NPT, (middle) BSPP, and (right) BSPT

2.5 Fill System with Anhydrous Ammonia (Task 5)

Anhydrous ammonia was used as the refrigerant for this system test. To prepare for the "proof of concept" test, the refrigeration contractor purged the two usable tubings three times with nitrogen gas to be sure any non-condensable gas was completely removed from the system. After purging, one pound of refrigerant was released into the two usable evacuated tubings by weighing out the refrigerant on a highly accurate scale on an inverted tank frame (Figure 16). The ammonia gas had a working pressure of 70 to 75 pounds. A steel frame had been manufactured to provide a safe dispensing environment for the inverted anhydrous ammonia tank. The tank holds about 15 pounds of liquid ammonia.

Lessons Learned

Use a certified refrigeration specialist to evacuate and charge the systems. The extra cost is worth mitigating the health risk hazards (Reference 3 TRANSCAER Training Manual, 2011).

Figure 16. Filling the Refrigeration Systems

3. Logging, Monitoring, and Telemetry Systems

3.1 Attach Camera and Anemometer to Tower

The metal tower located near the switch was used to mount the camera and anemometer for the system (Figure 17).

Figure 17. Anemometer and Camera System

The camera and anemometer logged photos of the switch heater from above every 10 minutes, and provided wind speed information.

Signal and power cables were routed to the instrumentation and logging box, which was attached to the side of the NS signal and switch case with permission of NS. Limited 120 volt power was supplied from the NS signal case, which was needed for this research to log information. It is not anticipated that future installations that are not research-related will need an outside power supply.

3.2 Signal Cables and Telemetry

Signal wiring was used to connect down-hole, track, switch plate, and ambient thermocouples to the instrumentation logging box (Figure 18). Trenches were dug and 2-inch diameter flexible conduit was placed in the trenches at a depth of at least 12 inches to minimize the potential for cable damage during the testing and logging of the systems.

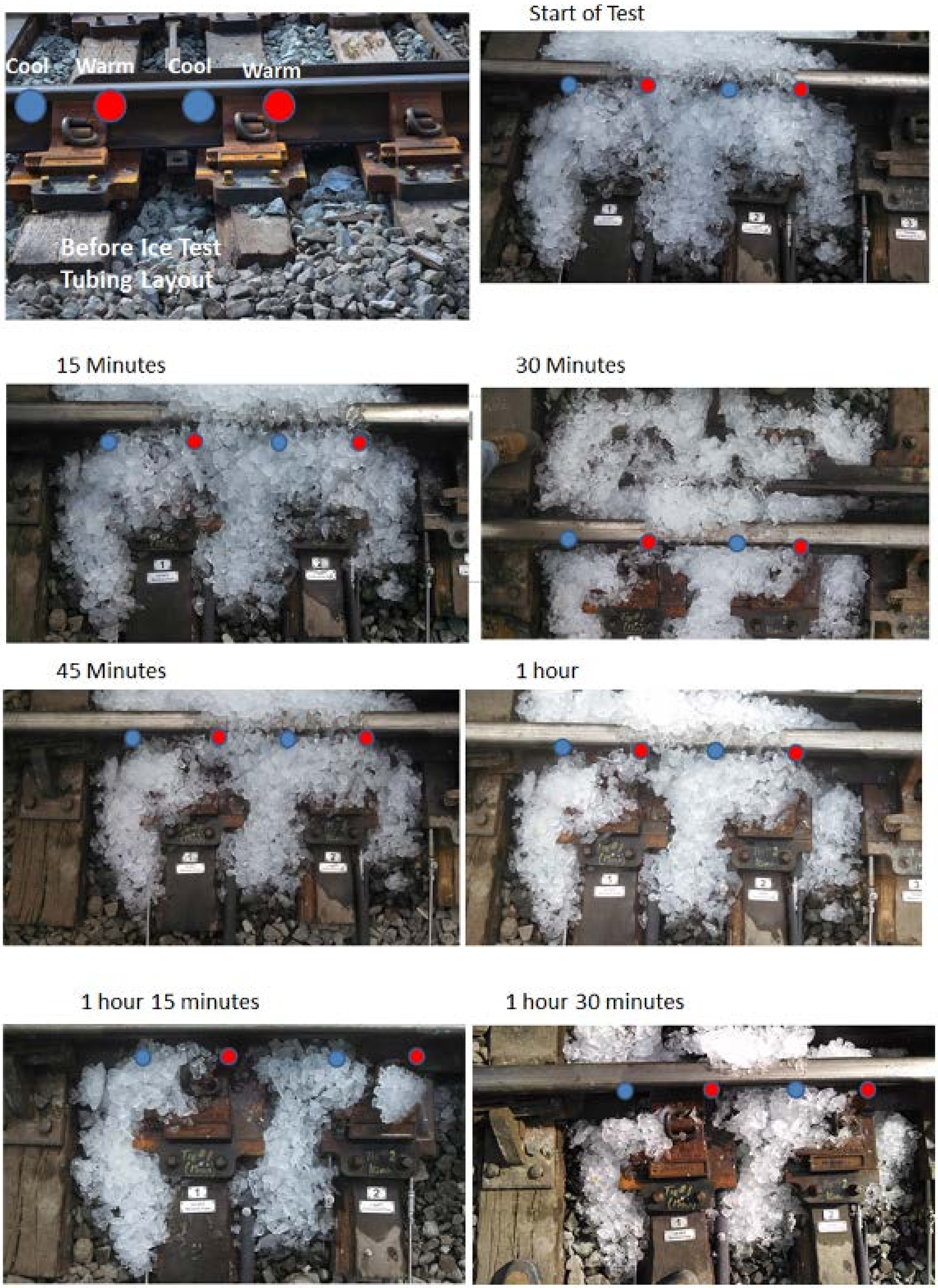
Figure 18. Preparation of Signal Wire and Installation of Switch Plate Thermocouples

4. Ice Test on Partially Completed System

The refrigeration contractor charged two of the down-hole refrigeration systems successfully, corresponding to Switch plate 1 (right side “R”) and Switch plate 2 (right side “R”). The tubing associated with the left sides of the two switch plates, “L”, did not hold pressure, so were “dead” and not charged with gas. As soon as they were pressurized, an ice test was immediately performed on the two charged systems, using approximately 240 pounds of ice which had been ordered for system testing. The ice was placed directly on Switch plates 1 and 2. It was observed that within 30 seconds of placing the ice on the two switch plates, the associated “R” crossover tubing was noticeably cold, which meant that liquid ammonia was passing through the down-hole tubing as it condensed and released heat into the switch plates. The “L” side tubings were at ambient temperature, with no condensate passing through them. The test continued for approximately 1 ½ hours, after which the ice was melted.

The ice melt test produced visual and instrumentation results, which indicated that the conceptual principles of the technology are sound, but additional work needs to be accomplished to complete the working system. Figure 19 and Figure 20 show the ice test and results.

Figure 19. Overhead View of Initial Ice Melt Test


Start of Test

15 Minutes

30 Minutes

45 Minutes

1 hour

1 hour 15 minutes

1 hour 30 minutes

Figure 20. Ice Test at Conclusion of First Installation Phase

5. Steps and Work Plan to Finish Installation of the System

Although the work accomplished during the initial site visit provided proof of concept verification to the viability of geothermal switch heating, the site did not have a working system. Because of technical issues encountered, another abbreviated site visit was conducted December 2014 to finish the installation. TTCI presented a second work plan to address the steps necessary to produce a working switch heater by the end of 2014. The basic steps included:

1. Refrigeration contractor repaired and replaced damaged valves and connectors with new stainless steel NPT rated parts. Tubing was ready to go at the initiation of Phase 2 of the installation.
2. The down-hole ballast weight for Well 2 had 15 pounds of steel added to it to keep the tubing taut during installation.
3. Tubing was bundled with duct tape instead of spacers to reduce insertion frictional forces as much as possible.
4. An additional trench was dug to the instrumentation cabinet from Well 2 instrumentation vault, and wiring was pulled to connect the two.
5. Onsite thermocouples were attached to the newly rebuilt tubing before down-hole tubing insertion.

The entire system underwent a final test before system signoff.

5.1 Install SealEase SnowProtec System

The Sealease Company provided its product for this project, through the efforts of Innovation und Verkehrstechnik Inc. Sealease SnowProtec systems use a brush type insulation and windbreak to retain heat that is released to the switch plates and track. This system was installed the initial evaluation was completed without any insulation advantages.

5.2 Data Collection and Reporting

TTCI downloaded information from logging equipment and site photography equipment for further evaluation by using remote telemetry and with site visits as necessary. Data was collected and forwarded to the project support organizations in the form of interim reports.

6. Introduction (Phase 2)

6.1 Background (Phase 2)

In February 2015, TTCI personnel met NS, Volpe, and various contractor personnel to complete the work and produce a working geothermal switch heater system at the NS switch yard site under FRA Task Order 303 Phase 2. Phase 2 work consisted of replacing wellhead transition assemblies, inserting tubing, and charging the tubing for Well 1 and Well 2, installing instrumentation, monitoring the system, and recording the results.

6.2 Objectives (Phase 2)

Passive geothermal switch heating using refrigerant ammonia was to be tested at a NS switchyard in Ohio, to determine if it is a viable (effective, efficient, economical) alternative to traditional active heating systems for keeping track switches free of ice and snow in winter.

6.3 Overall Approach (Phase 2)

Phase 2 of this research program consisted of rebuilding portions of the switch plate heating system, installing instrumentation, and monitoring the results to assess the dynamic effects of the topside and down-hole systems relative to each other. Phase 1 consisted of locating and preparing the research site, design and construction of components, instrumentation, installation and initial testing of the switch heater system, and monitoring of the initial system operations.

6.4 Scope (Phase 2)

Two sets of down-hole refrigeration tubing were replaced, crossover tubing was installed to connect the wells to the switch plates, and the system was charged with ammonia. Instrumentation was installed and the system was monitored for approximately 4 months in 2015. A still-photo camera was configured to communicate with the data logger to monitor overall switch plate heating system capabilities. A hand-held infra-red camera recorded ambient and system temperatures as dynamic effects were observed.

7. Activities (Phase 2)

7.1 Preparation for Installation Completion

The final installation of the geothermal switch heater system was completed in February 2015 (Figure 21). Geothermal Wells 1 and 2 had already been completed and were ready to receive the refrigerant tubing. A local refrigerant contractor had removed damaged wellhead fittings from the refrigerant tubing cluster and replaced them with higher quality fittings. In addition, the crossover tubing connection to the switch plates were redesigned to receive a 2-foot-long flexible connector to provide dynamic damping and fatigue reducing properties to the wellhead tubing pieces.

The tubing for Well 2 (the southern well) had been refurbished with new wellhead fittings in the contractor's shop, a newly designed (and heavier) ballast weight was attached to the bottom end of the refrigerant tubing, and down-hole instrumentation was secured to the tubing cluster before it was delivered to the site.

Figure 21. Phase 2 Installation of Geothermal Switch Heater

7.2 South Side (Well 2) Completion

Using lessons learned from Phase 1 work, the south side Well 2 wellhead transition assembly was replaced in the refrigerant contractor's shop in Cleveland before site work started to have a safe working space and to allow the epoxies and adhesives to be able to cure properly, since the outside temperatures were around zero degrees on track. The redesigned tubing ballast weight was attached to the tubing, and the pull rope was secured to the ballast before epoxying the weight onto the tubing string. Thermocouple sensors and wiring were secured onto the tubing every 20 feet and were extended to the wellhead transition tubing location. The tubing was rolled up and transported to the jobsite.

7.2.1 Placing Crossover Tubing

Snow was cleared away from the work area at the site, and the refrigeration contractor backed up a delivery truck to Well 2, which had been prepared with an instrumentation vault at ground level, identical to the vault that had been positioned over Well 1. The tubing was coiled up in a large roll for transport from the shop, and the ballast weight was positioned to go down the well first (Figure 22). The tubing was uncoiled down into the well by hand, and the tubing insertion process took less than 10 minutes. The insertion proceeded smoothly and the well cap was tightened into place. The total process was streamlined using lessons learned from Phase 1 work.

Figure 22. Installing Refrigerant Tubing into Well 2

7.3 North Side Well 1 Completion

The wellhead transition assembly joined the down-hole refrigerant tubing to the crossover tubing, then to the switch plate to form a continuous refrigeration-heating loop. It incorporated a refrigerant charging point, a system shutoff valve, electronic and dial pressure monitors, and convergence tubing for feeding more than one switch plate from a single refrigerant tube (Figure 23 left).

Wellhead transition assemblies were found to be faulty and leaking during the initial installation attempt in September 2014, and consequently, were rebuilt in the field (for Well 1) or in the shop (for Well 2) in February 2015. Parts used were upgraded to safely accommodate the corrosive effects of ammonia, in addition to being specification-built systems. This is important from a safety, functionality, and robustness perspective.

A flexible ammonia and pressure rated tubing was used between each assembly and the down-hole refrigerant tubing to provide ease of installation and resistance to fatigue cracking from dynamic track vibrations.

System insulation is critical to prevent heat loss before reaching the switch plates. Four methods of insulation were used on the crossover tubing and instrumentation vault:

1. Vault wall insulation – Rigid 1-inch insulation on the inside walls of the instrumentation vault.
2. Pipe insulation on the crossover tubes.
3. Spray foam insulation between the crossover tubing also served as a flexible support during dynamic track movement when trains are passing (Figure 23 right).
4. Polyurethane peanuts were used to fill the vaults after the system was complete. The peanuts can be vacuumed out for servicing the systems.

Figure 23. (left) Vault Interior Details (right) Tubing Support Insulation

7.3.1 Placing Crossover Tubing

Crossover tubing was attached to the wellhead assembly (Figure 24 right) on one end and to the switch plate on the opposite end. The tubing was constructed of ½-inch diameter stainless steel tubing that was attached to the wellhead assembly. Then it changed to a 2-foot-long flexible stainless steel tubing before it was attached to the wellhead. This was another design change from Phase 1, in which the tubing was attached directly to the switch plate and could result in leaks developing from flexure fatigue during dynamic track movement.

Two different configurations of crossover tubing were used: concurrent and reverse flow. According to the switch plate designer and manufacturer, the difference between the two systems is internal to the switch plate. The reverse flow configuration uses a single channel system internally, and the gas and liquid pass each other in opposite directions, whereas in the concurrent flow configuration, the gasses enter the switch plate near the top and the liquids exit near the bottom of the switch plate, so they do not directly pass each other. However, both tubing configurations use a single external supply and return tube for gasses and liquids for each side of the switch plate.

There were several operational challenges posed by the placement and configuration of the crossover tubes and flexible ends. First, dynamic track movement, tamping activities, foot traffic near the tubes, and even vehicular traffic could cause damage. This was addressed by placement of 2-foot-long flexible tubes between the ½ inch stainless steel crossover tubes and the switch plates. These flexible connections were designed to absorb vibrational and other stresses that rigid tubing could not. Second, since the passive flow system relies on a consistent downward gradient to route the cold fluid back down hole, any areas of the tubing which have inadequate slope or dips towards the well could cause pooling and blockage of the fluid. The infrared image in Figure 24 (left) could be indicating such a blockage in the north side Well 1 tubing. The portion of the tubing that turns and points downward is light, indicating the presence of warm gas, but portions of the horizontally oriented tubing are dark, indicating the possible presence of cold liquid. The liquid was not passing down hole and appeared to be stagnant.

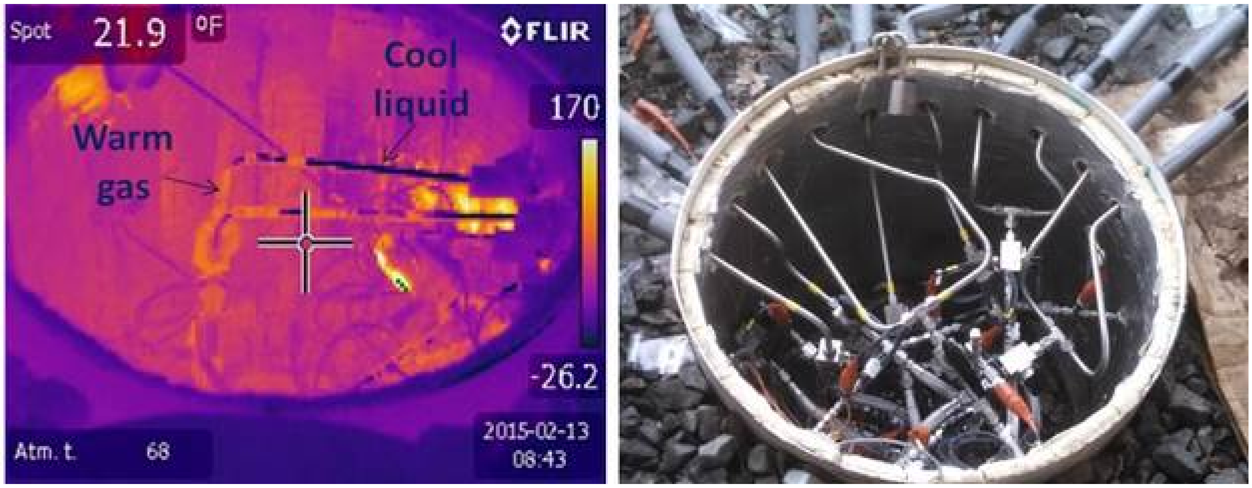


Figure 24. (left) Infrared and Visible Light Image of North Well 1 Tubing Indicating Hot and Cool Spots (right) Crossover Tubing attached to Wellhead Assembly

Third, the presence of junctions in the tubing could also cause blockage and may need to be redesigned. The original configuration of these junctions utilized a stainless steel wye, which may offer less resistance to liquid flow if the slope is adequate; however, these stainless steel wyes were not available for use at the time the system was installed. The 90-degree T-junctions shown in Figure 25 may cause flow restriction at the junction.

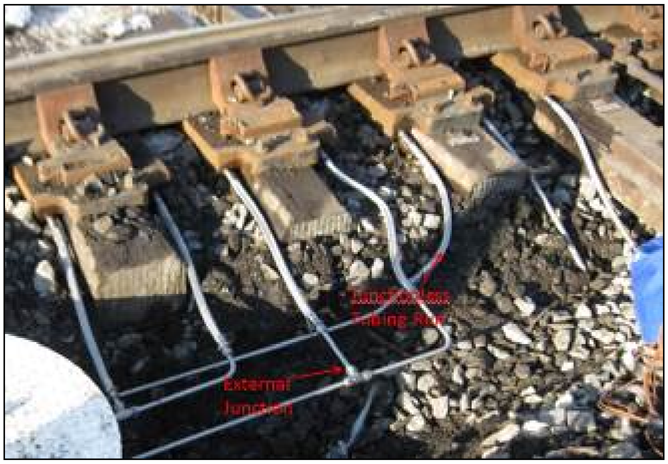


Figure 25. Well 2 Crossover Tubing Configuration to Switch Plates South Side

7.4 Charging the Tubing with Ammonia

After the tubing was in place, each system was pressure and vacuum tested with nitrogen overnight before filling with ammonia (Figure 26 and Figure 27). The nitrogen also served to capture and displace any air and water vapor that might be present before the systems were charged with ammonia. Nitrogen purging was performed three times, then ammonia was introduced to the evacuated system.

Figure 26. Purging the Systems with Nitrogen

Figure 27. Charging the Heating Systems with Ammonia

8. Instrumentation

Instrumentation included a Campbell Scientific CR3000 data logger, a low-light camera, an anemometer, and pressure transducers on each ammonia tube. Thermocouples were epoxied onto the refrigeration tubing every 20 feet in each well, and also were placed on heated and unheated plates, the web of the rail, in the ballast, in one of the vaults, and in the instrumentation case.

Thermocouple cable and signal wiring were used to connect down-hole, track, switch plate, and ambient temperature thermocouples and pressure transducers to the instrumentation logging box (Figure 28). Of 29 thermocouples originally placed in the wells and above ground, 23 are still recording data.

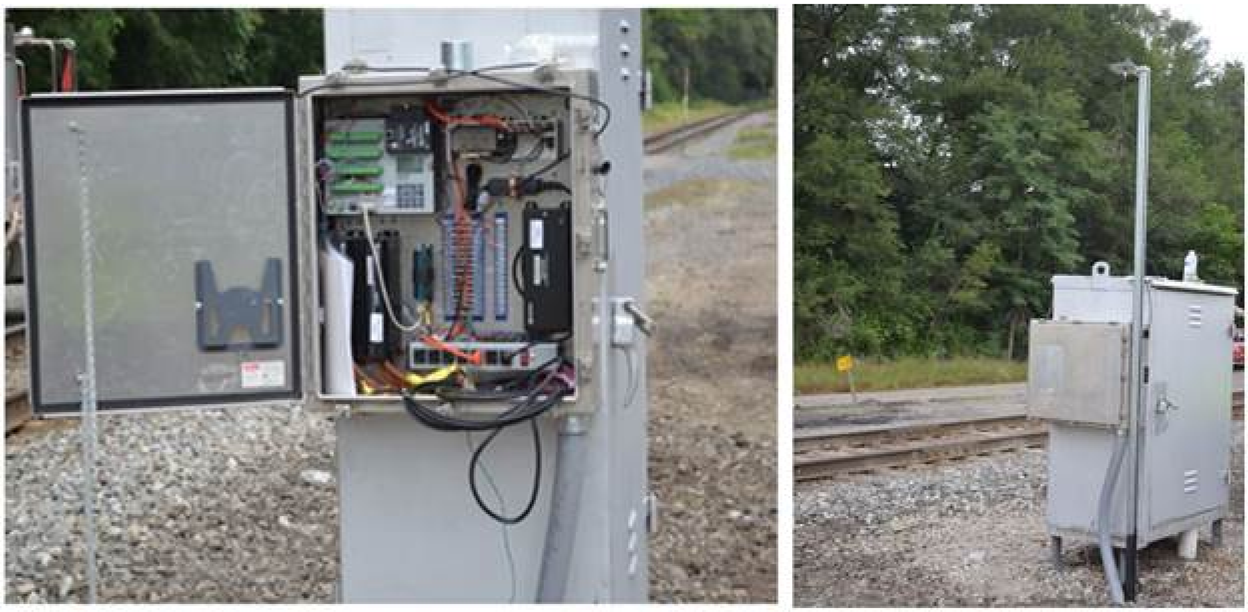


Figure 28. Instrumentation Logging and Remote Telemetry Box

Trenches for the conduit were dug and 2-inch diameter Liquitight flexible conduit, as well as 2-inch Schedule 80 conduit pipe and fittings, were placed in the trenches at least 12 inches deep to minimize the potential for cable damage during the testing and logging of the systems. Conduit runs were made from the instrumentation case to the each of the wellhead vaults.

The Honeywell absolute pressure transducers are rated at a maximum pressure of 200 psi, and they were connected in a standard 4-20 mA current-loop configuration with shunt resistors to sense voltage at the data logger. They used 200Ω, 0.05 percent high precision metal-film shunt resistors in the loop for voltage sensing. Data from the pressure transducers was read into the data logger via a Campbell AM26/32B multiplexer. The offset and gain of each transducer was recorded and these values were used to compensate the readings in the data logger software.

Each pressure transducer was calibrated and offset recorded, and compensated for in the data logger software. Type K thermocouples were used, and cold-junction compensation was provided by the data logger. A pair of 25-channel multiplexers, connected to and controlled by the data logger, was used to read the large number of thermocouple inputs. The data logger is connected to a wireless 4G modem, through which transducer data and photographic images can be downloaded remotely via cellphone connection.

The pressure transducers used in the installation failed prematurely because they were not compatible with anhydrous ammonia (although they were advertised as being compatible with refrigerants). A better choice would have been the stainless steel bodies and diaphragms that are designed specifically for use with corrosive gasses and liquids.

Data from all transducers was collected every 10 minutes. Photographs of the site from the camera were taken once every 30 minutes, to conserve disk storage and shorten download time.

Although some of the pressure transducers failed, the pressure was still easily estimated from published ammonia pressure-temperatures charts such as shown in Figure 29. The pressure of the system is directly proportional to the vapor pressure of the ammonia at ground temperature (which varied from approximately 55°F to 45°F).

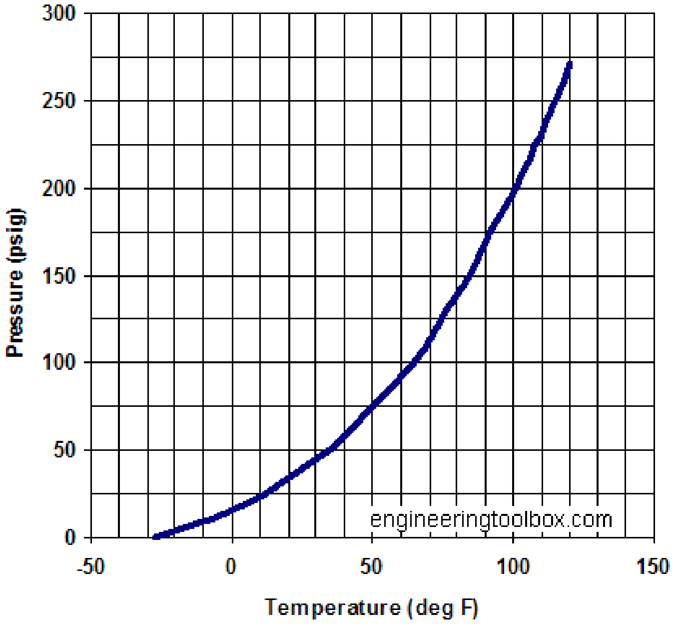


Figure 29. Typical Ammonia Pressure/Temperature Chart

9. Long-Term Monitoring

An overhead camera monitored the snowfall and switch plate conditions on the system 24 hours per day for approximately 3 months in early 2015. Thermocouple data was recorded for down-hole borehole temperatures, in addition to vault, switch plate, and rail temperatures.

9.1 Overhead Camera Observations

A video camera was mounted on a nearby abandoned catenary support tower with a full view of the switch. The camera was configured to communicate with the data logger over a serial communications link, and an external SD card was provided for image storage. Remote access to the data logger was provided by a wireless 4G modem. The video camera showed that four of the switch plates worked well during the entire test period of approximately 3 months; one switch plate appeared to have one side working and one side working marginally. Figure 30 shows photographs of the overhead camera setup and several overhead photographs taken during the test.

Figure 30. (a) Overhead Camera and Anemometer Setup on Old Catenary Tower (b) Feb. 14, Initial Overhead Photos show five Switch Plate Heating Systems Working (c) Feb. 20 after heavier snow (d) Mar. 1 system still working (e) Mar. 4, switch plates are clear

9.2 Surface and Down-Hole Temperature Observations

The soils onsite consisted of saturated gravelly coarse sand down to approximately 30 feet, then silty gravelly sand to 33 feet, and finally various percentages of silty lacustrine clay or clayey silt to 150 feet. Thin horizontal shale stringers and clay lenses were present from 150 to 175 feet.

Groundwater temperatures are influenced by cold refrigerant temperature and flow rate, and by warm geothermal flux into the cooler zone near the well. Temperatures of water, soil, or a combination of the two may influence the recovery rate of the well.

Down-hole temperatures do not correlate directly with air temperatures, except that the passive system will cease operation at approximately 35°F, and so will not be cooling the geothermal well. Thermal well rebound begins at that point.

Down-hole temperatures were monitored and recorded every 20 feet vertically, starting at the wellhead (Figure 31). For each date, an array of temperatures was recorded, which shows a more tightly clustered variation before the geothermal heating systems were started (Feb. 8, 2015), and becoming more spread out over time. Initial down-hole temperature range for the north well varied from approximately 54°F to 47°F before the systems started. After the track had been warmed for 3 weeks, temperatures appeared to reach minimum temperatures ranging from 44°F to 38°F; then began a slow warming trend.

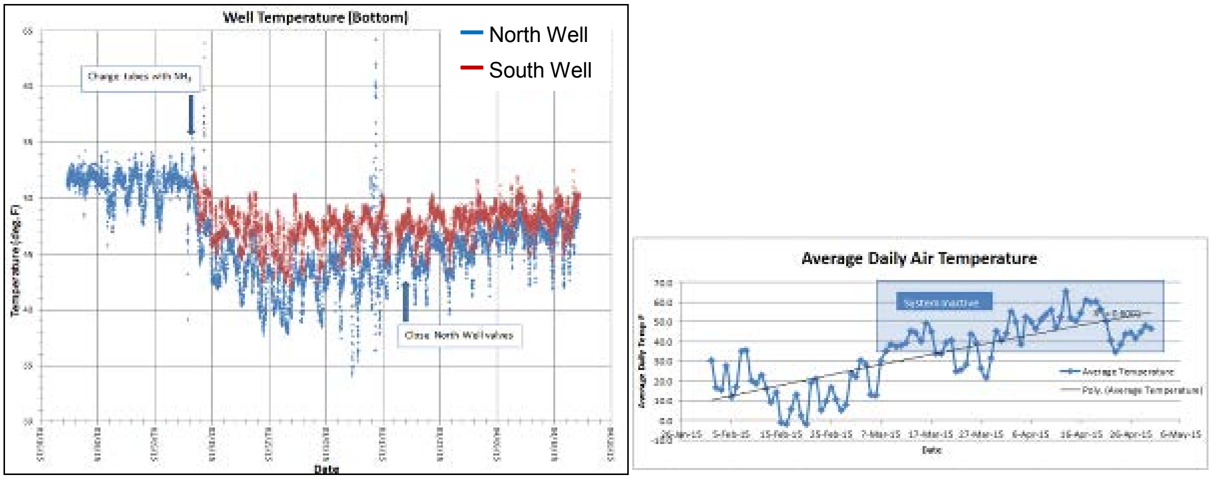


Figure 31. (left) Well Bottom Temperatures (right) Average Daily Air Temperatures

The south well temperatures averaged approximately 46°F to 48°F near the bottom during operation, and the north well temperatures averaged 41°F to 46°F, with 2 to 5 degrees temperature difference between the two well systems. There were more working heating loops functioning in the north track, which may have contributed to the difference, but a more efficient heating system may have caused the difference. Temperature differences between the two wells seemed to merge slowly after the north well valves were shut down on March 20, 2015.

9.3 FLIR Infrared Camera Photos

The FLIR infrared camera was used onsite during and after system installation to assess performance of each switch plate and to detect thermal losses from insulation and electronic equipment hot spots. The switch plate layout in the following images can be generally correlated to Figure 32, which refers to the north (N) and south (S) sides of the track.

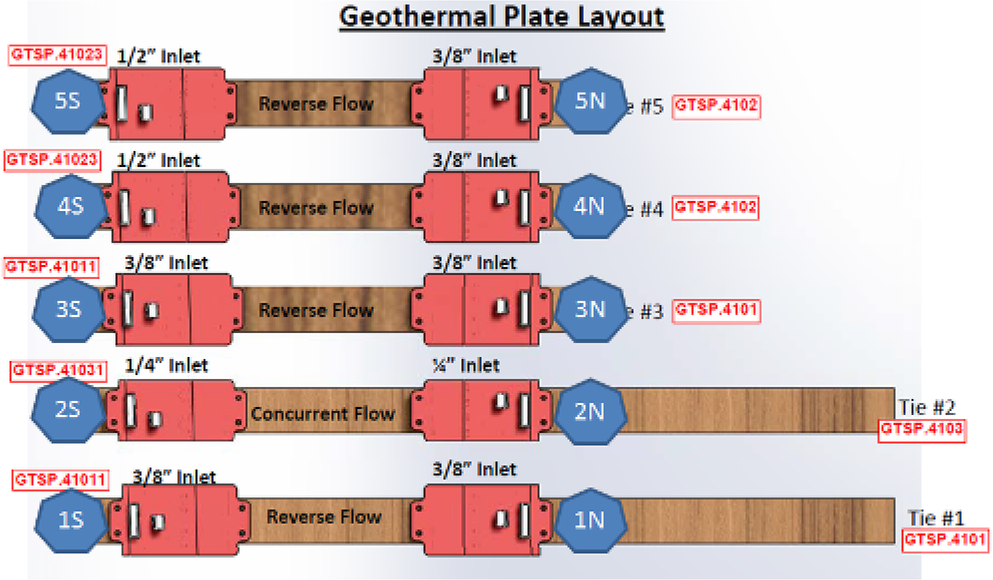


Figure 32. Switch Plate Designations

The infrared images indicate that of the 20 individual heating systems (two per switch plate) in this study, 9 of them appeared to be performing well and consistently. Switch plate 1N sides a and b (left and right) were on the north side (Well 1).

Some of the infrared photos were blurry, not discernable, or unidentifiable, so only the images that are identifiable and usable are discussed in this section.

Figure 33 shows the north side switch plates as viewed from 1N to 5N, then from 5N to 1N; Plates 1 and 3 were working well on both field and gage sides. Plates 2 and 4 were warming marginally on the field side (not enough to melt snow at very low temperatures). Plate 5 was not working on half of the plate, but it was working well on the other half.

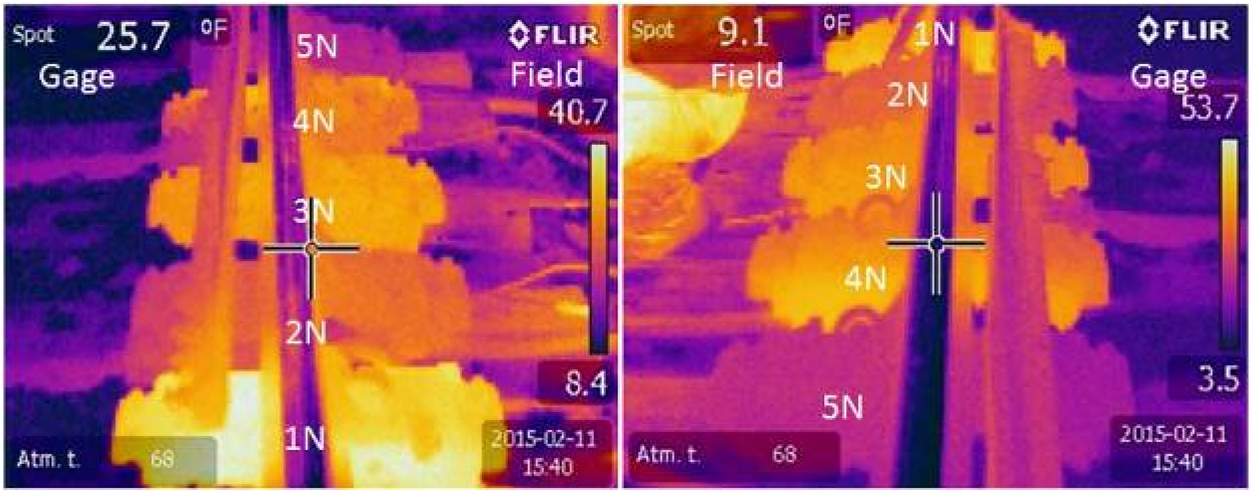


Figure 33. Infrared Images of North Side Switch Plates 1–5

Figure 34 shows a photograph and infrared images of switch plate 1N; the infrared images show the gage and field sides were working well and were heating the switch plate and the rail. An insulating compound or method may improve the heat retention properties of the switch plates and rails and may result in better heat conduction to the rail.

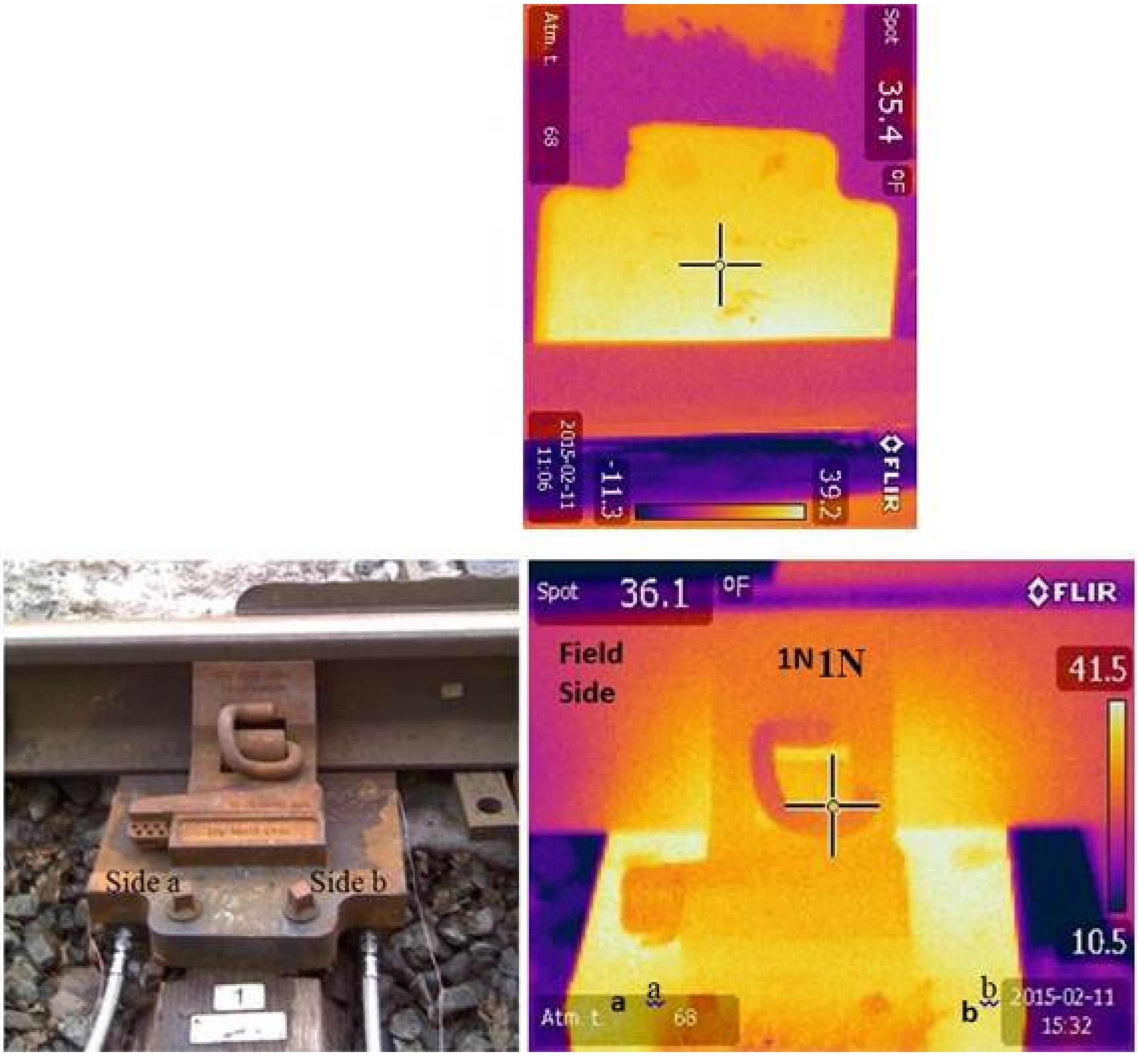


Figure 34. (top) Gage Side Infrared Image (bottom left) Site 1N Switch Plate (bottom right) Field Side Infrared Image

Figure 35 shows a photograph and infrared images of switch plate 2N; sides a and b were working, but as the infrared image shows, they were not working as well as switch plate 1. There may have been more heat loss from the flexible tubing (notice the brighter color for 2N tubing), but it is not apparent why this might be. Switch plate 2N condensation appears to have occurred right at the vapor entry point rather than through the entire switch plate matrix, which could indicate a low flow situation for either vapor or liquid, or both. Since it was occurring on both sides of the plate, it could have been a switch plate design issue. It did not appear to be heating the rail well.

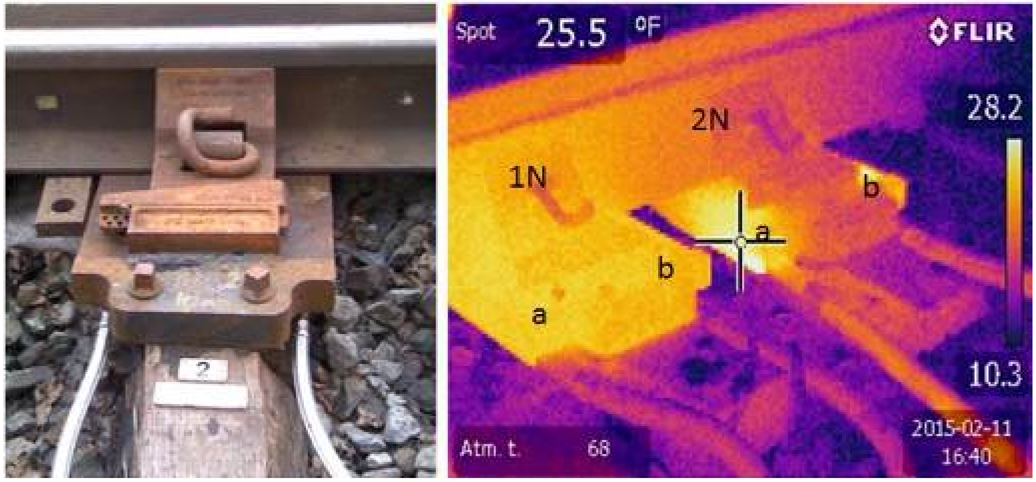


Figure 35. (left) Switch Plate 2N (right) Infrared Image of Switch Plates 1N and 2N – only 2N is working

Figure 36 shows switch plate 3N sides *a* and *b* were working well. Both sides appeared to be heating evenly, and the rail was heating up as well. The tubing had a constant slope down to the well, and it had a few bends in the tubing.

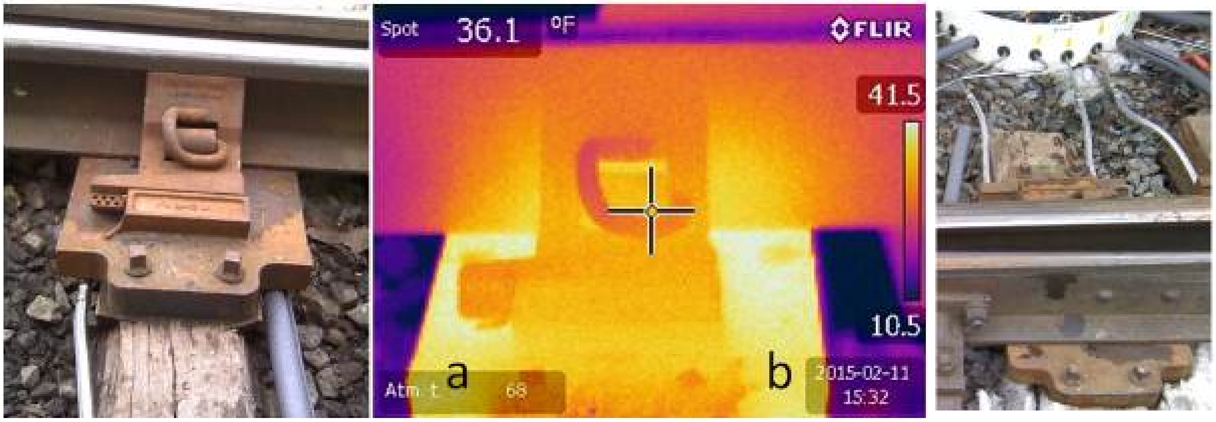


Figure 36. (left) Switch Plate 3N (middle) Infrared Image of Switch Plate 3N (right) Photo of Tubing from Switch Plate 3N to Well

Figure 37 shows switch plate 5N sides a and b; although b appeared to be the only side that was heating up. Since the switch plate design was the same for both sides, it appeared that an external influence may have caused issues for side a. This could have been inadequate slope causing vapor lock, pooling of liquid in a low spot, flow constriction at a T-junction in the tubing, or other issues.

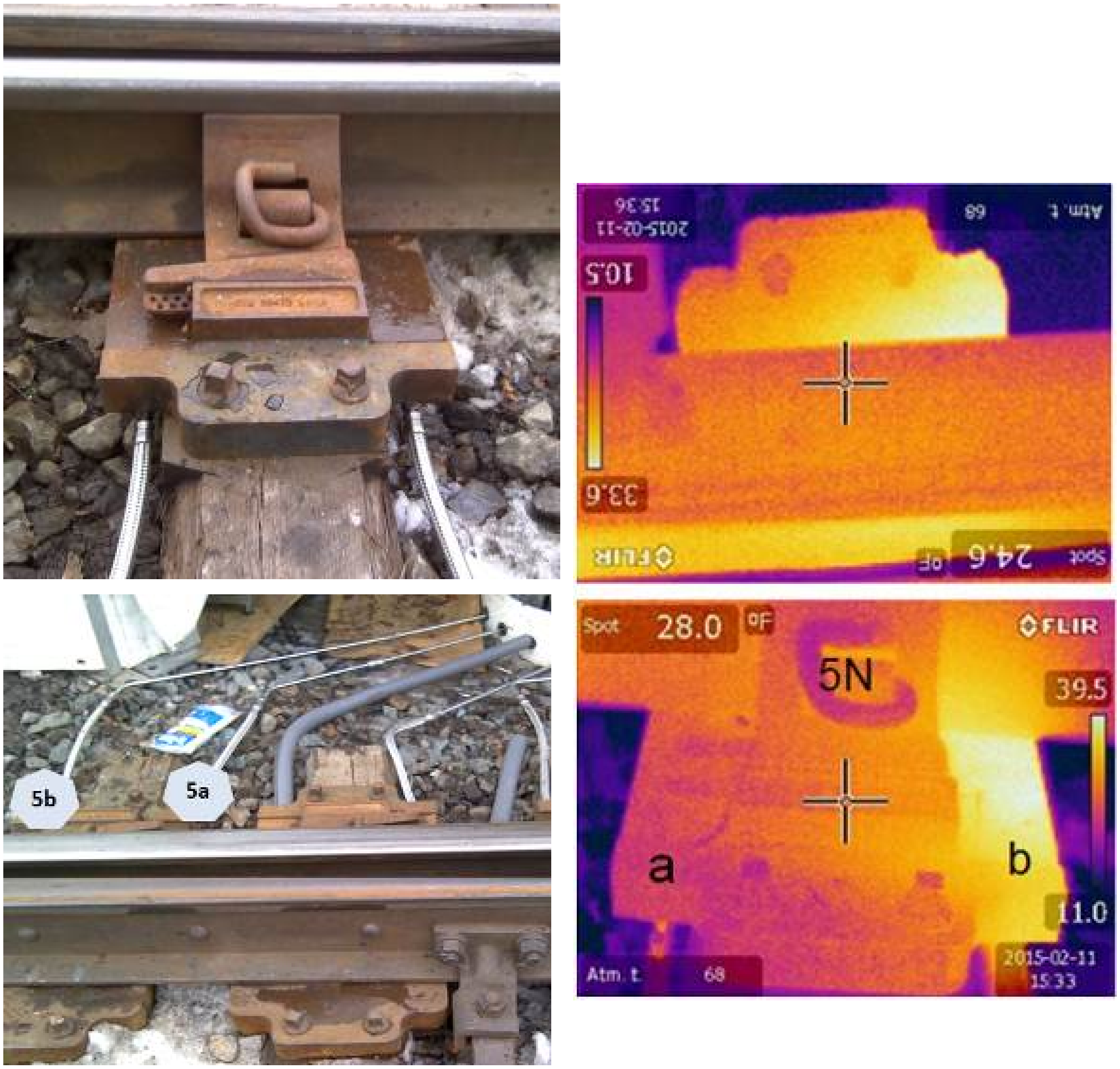


Figure 37. (left) Switch Plate 5N (right) Infrared Images of Switch Plate 5N

Figure 38 shows the south side switch plates as viewed from 1S to 5S. The infrared image shows 1S was not working, 2S, 3S, 4S, were marginally working, and 5S was working well on side *b* and fairly well on side *a*. Figure 39 shows a photograph of the sets of tubing for switch plates 5S and 4S. Both sets of tubing had a good slope from the switch plate down to the wellhead. The infrared image shows switch plate 5S was working well on both sides, but switch plate 4S was not working on either side.

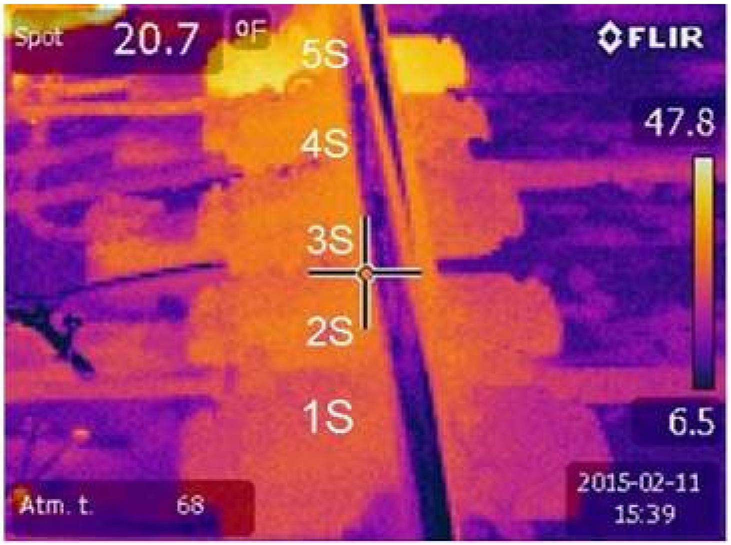


Figure 38. View of South Side Switch Plates 1–5

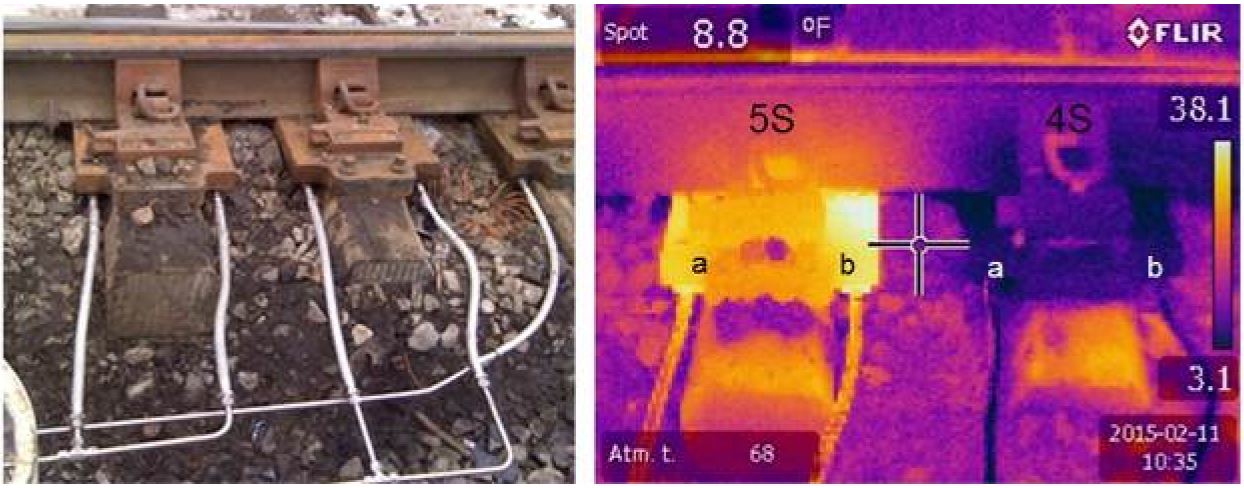


Figure 39. (left) Switch Plates 5S and 4S
(right) Infrared Images of Switch Plate 5S and 4S

10. Conclusions and System Improvement

The results of this research initiative indicate that geothermal switch heating technology is a viable alternative to traditional active heating systems for keeping track switches free of ice and snow in winter. Additional development is necessary to reduce installation and system costs, and to make the system more efficient by improving the design of its components. Specific recommendations include heat source improvements, tubing vapor lock design improvement, switch plate design changes, and analyzing the use of carbon dioxide versus ammonia for the working fluid using this study as a benchmark.

Heat Source Improvements—The cost of drilling geothermal wells may be worthwhile in many instances, particularly if the well can be shallow and drilled in a high conductivity sand or gravel that has a good hydraulic connection with a moving stream or having a hydraulic gradient to keep cold water moving away from the well. Water has much better heat capacity than earth materials, and it has the advantage of good convection and conduction under favorable circumstances. However, many switchyards do not have these subsurface advantages and other heat sink designs may be worth considering.

Instead of a vertical drilled well, a sloped series of tubes in a lined trench or pit may be worth testing; the lined pit can be filled with ballast, then filled with water and covered over with liner material, then earth. The thermal capacity of the pit would need to be greater than the thermal needs of the switch for each season.

Tubing Vapor Lock Design Improvement—The current tubing design consists of a single tube through which both liquid and vapor must pass. While this design seems to be adequate for vertically oriented large diameter tubing, one of the potential issues noted may be a vapor locking effect in which the flexible tubing dips and the liquid pools up. One variation worth considering might be to run a small diameter tube for the gas on top of a larger diameter tube for the liquid return. The vapor inlet would enter the switch plate at the top while the liquid return would be at the bottom of the switch plate. Vapor locking potential would be greatly reduced. The use of "Y"s rather than "T"s for junctions may also reduce fluid turbulence and drag. A competent fluid dynamics specialist may be a valuable addition to the research team.

Switch Plate Design Improvement—The many variations and design changes in the switch plates, working fluid, tubing slope and channel length, fluid flow rate, heat exchange rate of a switch plate at different temperatures, and other relevant topics could be researched efficiently and quickly using a series of well-planned bench tests. A high quality testing plan could reduce the cost of researching towards an efficient system design by a significant factor. A constant temperature warm bath heat source and ice bath heat sink would provide constant conditions for heat flow calculations, as well as a Doppler flow meter for the liquid return and other bench test parameters, which can be kept constant while testing other parameters.

Use of Carbon Dioxide versus Ammonia—The issue of using carbon dioxide versus ammonia for a working fluid was discussed at length while planning the project. The denser, less viscous carbon dioxide with its higher mass flow properties has certain advantages over ammonia, while the higher heat capacity, lower working pressure, and other more favorable enthalpy properties of ammonia are also worth considering. An in-depth analysis of both fluids, combined with the bench test previously mentioned, may help in the decision-making process.

11. References

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Abbreviations and Acronyms

CP	Canadian Pacific Railway
CPT	Cone Penetration Test
FRA	Federal Railroad Administration
MP	Mile Post
NS	Norfolk Southern Railway
TTCI	Transportation Technology Center, Inc. (the company)
Volpe	John A. Volpe National Transportation Systems