SYSTEMS FOR ELECTRICAL POWER FROM CO-PRODUCED AND LOW TEMPERATURE GEOTHERMAL RESOURCES

Timothy Reinhardt, U.S. DOE, Geothermal Technologies Program, Washington, D.C.
Lyle A. Johnson, Rocky Mountain Oil Test Center, Casper, Wyoming
Neil Popovich, National Renewable Energy Laboratory, Golden, Colorado

ABSTRACT

The Geothermal Technologies Program (GTP), the Rocky Mountain Oilfield Testing Center (RMOTC), and the National Renewable Energy Lab (NREL) are working together to advance the production of power from coproduced and low temperature geothermal resources. To this end, and through a collaborative effort, RMOTC is being used as a test-bed for promising low temperature geothermal power production technologies. These technologies produce electricity by leveraging existing oil and gas field infrastructure as well as the resource geofluid which is coproduced in the process of harvesting hydrocarbons. GTP is providing the direction and oversight for the work. RMOTC is providing the facility, resource and manpower to operate the test units, while NREL is providing the technical analysis and insight to help overcome challenges currently faced with low temperature geothermal power production systems. Details of the role of each participant are given in the paper.

Presently, the initial geothermal power production unit being tested under the collaborative program is an air-cooled nominal 250 kW Ormat unit installed at RMOTC. To date, the total produced power from the unit is 1,918 megawatt hours of power from 10.9 million barrels of coproduced hot water. The online percentage for the unit, eliminating downtime caused by field activities, has been at 97%. This Ormat unit will continue to be operated at RMOTC for an additional 2 years under the collaborative agreement with DOE's Geothermal Technologies Program.

Additionally, infrastructure at the RMOTC test site has been prepared for the installation of a second, water-cooled nominal 250 KW Pratt & Whitney unit that is scheduled for delivery in late January 2011. Under this program, the second, water cooled unit will be installed and tested for 3 years. This added capability will provide operational data and experience that can be transferred to potential users of air or water cooled systems in both oil/gas fields and low temperature geothermal settings.

Looking to the future, RMOTC will continue geothermal testing, develop a test facility for smaller geothermal systems, develop plans for EGS applications and testing, and implement new initiatives. In parallel, GTP will provide funding for continued testing of program related geothermal activities at the site. The geothermal subprogram will also continue to provide guidance and oversight on all projects, as well as engage with National Labs, universities and industry to foster advances in technology by implementing innovative concepts and ideas at the RMOTC test site. NREL's future activities will be focused on addressing current challenges to the geothermal systems. NREL's efforts will be focused on recording/analyzing data from Organic Rankine Cycle (ORC) and other geothermal power systems, and implementing improvements to the systems to improve their performance and promote the use of these renewable low temperature geothermal energy technologies. Ultimately, these plans are an attempt to provide the geothermal community with the means to achieve development and widespread deployment of economically viable, innovative, and scalable technologies that will capture a significant portion of the low temperature and coproduced geothermal resource base over the next two decades.

BACKGROUND

During the 1970's, the publicly available information concerning geothermal power production and resources was limited. In response to this less than favorable environment for geothermal industry growth, the U.S. Government initiated the geothermal research and development (R&D) program. The intent of the geothermal program was to understand geothermal resources, improve geothermal science and engineering technology, and to ensure information was available to developers, utilities, financial institutions, regulators, and other stakeholders necessary to spur development of the industry.

Today, the Geothermal Technologies Program (GTP), as that initial R&D program has come to be known, develops innovative geothermal energy technologies to find, access, and use the Nation's geothermal resources. Through research, development, and demonstration efforts, the GTP is working to provide the United States with an abundant, clean, renewable energy source. The GTP works in partnership with industry, other government agencies, academia, and DOE's national laboratories to establish geothermal energy as an economically competitive contributor to the U.S. energy supply. In pursuit of these goals, the program has partnered with RMOTC and NREL to demonstrate technically feasible and economically viable geothermal energy production from oil and gas wells at the RMOTC test site.

NREL's role in the GTP program is based on NREL's overall mission to develop renewable energy and energy efficiency technologies and practices, advance related science and engineering, and transfer knowledge and innovations to address the nation's energy and environmental goals. NREL seeks to accomplish this via its efforts to

evaluate the state of the geothermal industry and to promote the geothermal industry thru technical analysis and information dissemination. NREL's function in this specific project is to help DOE evaluate new geothermal technologies and address current challenges facing these technologies. In this role, NREL is designing and installing data monitoring systems that will be used by NREL to collect and analyze data on geothermal power plants operating at RMOTC. Current geothermal challenges that NREL is addressing are related to power output improvements throughout the year and improving power output in warm climate operating environments.

The data presented in this paper is the result of both a Cooperative Research and Development Agreement (CRADA) between Ormat Nevada, Inc. and the DOE and a collaborative agreement between RMOTC and DOE's GTP to extend and expand testing of geothermal systems. In RMOTC's oil field and many oil fields in general, a large volume of water is produced with the oil. In a majority of these oilfields, water is a waste stream and has a temperature below 250 °F. Because of the large volume, modeling predicts that this water should be hot enough to be capable of generating significant electrical power for facility consumption. To verify this concept, DOE's Rocky Mountain Oilfield Testing Center (RMOTC) and GTP developed a program to test power generation from oil field waste streams.

The initial geothermal power production unit installed was an air-cooled, factory integrated, skid mounted standard design 250 kW Ormat Organic Rankine Cycle (ORC) power plant. This unit was installed at the Naval Petroleum Reserve No. 3 (Teapot Dome Oil Field), north of Casper Wyoming. It was put into service in September, 2008 and operated until February 2009 when the unit was shut down because of operational problems. During this initial period (Phase 1) the unit produced 586 MWhr of power. Operational problems that caused Phase 1 termination resulted in changes in the control system, repairs to the generator/turbine system and field and well system upgrades. The unit was restarted in September 2009. The results since restart, Phase 2, are presented in this paper.

The field in which the Ormat and future units will be installed is a 9,481-acre operating stripper well oil field offering a full complement of associated facilities and equipment on-site. There are 730 well bores in nine producing reservoirs ranging in depth from 250 to 5,500 feet at the field. The wellbores consist of 150 producing wells with the remainder temporarily shut-in or being used for testing. In this field, two formations, the Tensleep and Madison, produce sufficient hot water for the practical generation of geothermal energy. Current produced water from the Tensleep formation is 45,000 barrels of water per day (BWPD), with an average production temperature of ~200°F. The Madison formation is a non-oil producing zone with a flowing resource of 200-210°F water. It is projected that with minor work on existing wells, the rate for the combined Tensleep and Madison produced water would be between 126 and 210 MBWPD.

RESULTS AND DISCUSSION

Geothermal energy production, a $1.5 billion a year industry, generates electricity or provides heat for direct-use applications including aquaculture, crop drying, and district heating. Continuing to build on the technical research base that has been developed over the last several decades, GTP, RMOTC and NREL's activities will provide information and understanding necessary to create new and more efficient and reliable technologies and to enable the U.S. geothermal industry to compete for base-load electricity generation. Recent funding increases, including the American Reinvestment and Recovery Act (ARRA) of 2009, have acted as catalysts that will allow the GTP and its partners to pursue these goals.

The ARRA provided funding for efficient and renewable technologies, including geothermal. Through ARRA, GTP received approximately $380 million to reduce geothermal development risk by investing in a wide portfolio of geothermal programs; 151 projects were selected for negotiation. Using ARRA resources, GTP funded 10 projects to demonstrate energy production from oil and gas fields, geopressured fields, and low temperature resources in a technically feasible and economically viable manner. In total, over $18 million dollars was made available on a cost-share basis for these projects.

Early in 2010, additional financial support was made available through a Funding Opportunity Announcement (FOA), in the following topic areas: low temperature geothermal fluids at temperatures up to 300°F (~150°C); geothermal fluids produced from productive, unproductive, or marginal oil and gas wells, mining operations or other hydrocarbon or mineral extraction processes; and highly pressurized or "geopressured" fluid resources that show potential for cost-effective recovery of heat, kinetic energy, and gas. Out of this FOA process, 7 awardees were selected, with total DOE cost-share of up to $20 million dollars.

In light of this more promising climate for low temperature geothermal development, the present collaboration takes on an even greater importance. The preliminary results below demonstrate that significant results can be achieved over a short time-span and with relatively modest funding. Further data collection and analysis, particularly after commissioning of the second unit, will provide invaluable knowledge to the geothermal community. This is especially true of Levelized Cost of Electricity (LCOE) reductions as they apply to coproduced geothermal applications.

The power output results of the Ormat unit installed at RMOTC are divided into two operational phases. The Ormat unit was put into operation at RMOTC in September 2008 as an air cooled unit. The first operational phase was from September 2008 to February 2009. The first operational phase includes the period from initial startup of the unit until shut down for repair and maintenance and field related

work. The second operational phase is from September 2009 to the present. For Phase 1, the net power output averaged 171 kW with a range of 80 to 280 kW. The operational data for the two phases is listed in Table 1. During Phase 1, the unit produced over 586 megawatt hours of power from 3.0 million barrels of coproduced hot water. The online percentage for the unit during this period was 91% considering both field and unit related down time. The down time attributed to unit issues was only 3%. Therefore, the unit had a 97% online percentage. The system related downtimes were largely the results of the operator's learning curve until the shutdown in February 2009.

To date, Phase 2 has averaged 185 kW net power output with a range of 80 to 275 kW, Table 1. During this time, the unit has produced over 1,332 megawatt hours of power from 7.8 million barrels of coproduced hot water. Total produced power from the unit is 1,918 megawatt hours of power from 10.9 million barrels of coproduced hot water. The online percentage for the unit, eliminating downtime caused by field activities, has been a 97%.

The results of this testing have been very promising in demonstrating power production from coproduced fluids in an oil field. Further testing and system improvements should provide even greater and more consistent power production. The online percentage, which currently stands at more than an acceptable 97%, may even be increased by a percentage or two.

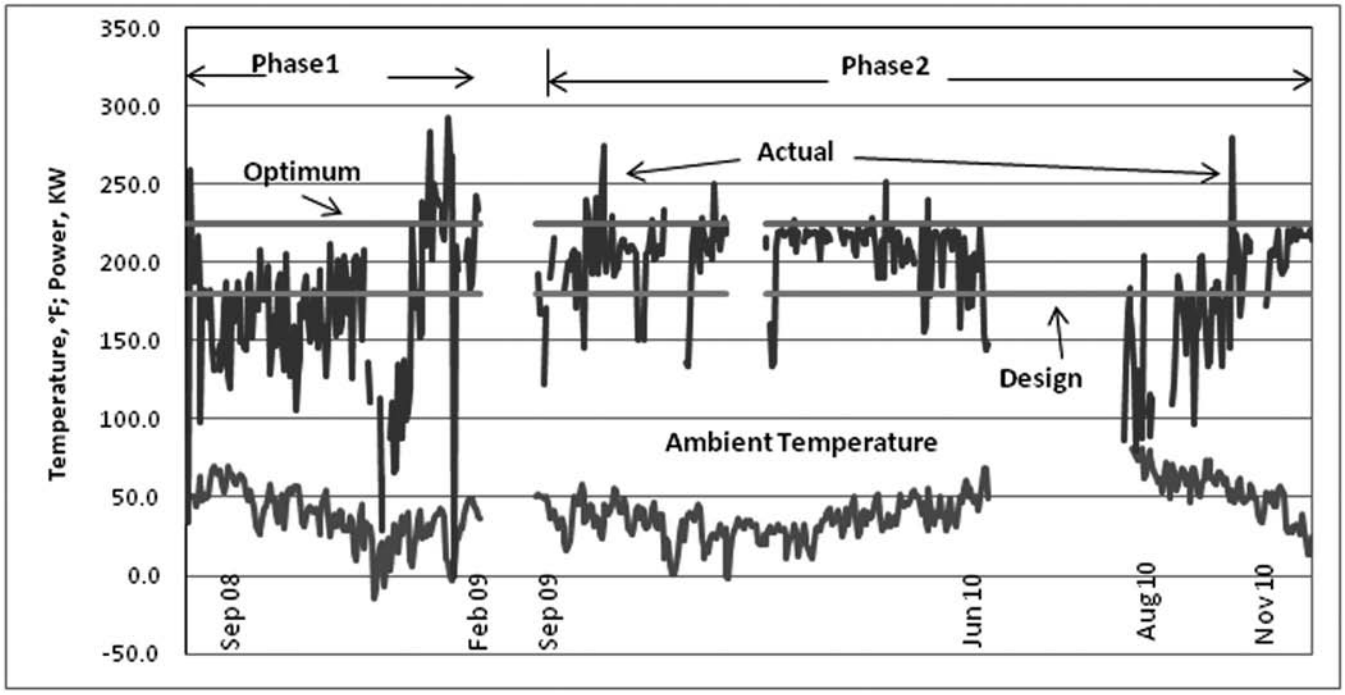

Figure 1: Operating Parameters

Table 1. Design and Operational Data

	Design	Operational Results	
		Phase 1	Phase 2
Flow rate, bpd	40,000	12,000 to 40,000	11,000 to 50,000
Total hot water used, bbl		3,047,192	7,860,737
Inlet water temperature, °F	170	195 to 198	196 to 198
Outlet water temperature, °F	152	80 to 170	47 to 150
Average ambient temp., °F	50	-7 to 85	-2 to 81
Generator gross power, kW	180	105 to 305	105 to300
Daily avg. net power output, kW	132	80 to 280	80 to 275
Overall avg. net power, kW		171	185
Total power produced, MWhr		586	1,332

FUTURE PLANS

GTP's Low Temperature and Coproduced subprogram intends to provide the geothermal community with the means to achieve development and widespread deployment of economically viable, innovative, and scalable technologies that will capture a significant portion of the low temperature geothermal resource base over the next two decades. In order to achieve this goal, the subprogram has identified three avenues, or activity areas, that must be pursued in order to turn this goal into a reality. These areas are advancing technologies, fostering deployment, and informing policy. The RMOTC project will continue to address challenges in both the advancing technologies and fostering deployment areas of the subprogram portfolio.

The GTP subprogram will work to achieve its low temperature power production goals thru a coordinated effort with RMOTC staff. The program will provide funding for continued testing of program related geothermal activities at the site. In addition, future Financial Opportunity Announcements (FOAs) may become available to help companies implement unit testing at the facility. Finally, the subprogram will provide guidance and oversight on all projects, as well as seek to discover and employ innovative concepts and ideas at the RMOTC test site, specifically those related to system improvements. RMOTC plans to continue to operate the unit for an addition 2 years under the collaborative agreement with DOE's Geothermal Technologies Program. Also under this program, a second power generation unit of the same nominal generation capacity but water cooled will be installed and tested for 3 years. This period of performance will provide operational data and experience to transfer to potential users for both air and water cooled systems in both an oil field and low temperature geothermal settings. During this time, RMOTC will be developing a test facility for smaller geothermal systems and developing plans for EGS applications and testing.

NRELs future geothermal activities on this low temperature/coproduction project will be focused on data collection, data analysis and resolving fundamental challenges associated with geothermal technologies. The instrumentation and data systems will be installed on the Ormat and UTC ORC units in the second quarter of 2011. The sensors being procured will monitor temperatures, pressures and flows of the brine and working fluids. Sensors will also be installed to monitor the power output of the unit and the parasitic power consumed by the unit. A weather station will be installed to collect data on ambient weather conditions and the effect of ambient conditions on power output of the unit. Baseline data and long-term data will be collected and stored in NREL databases. Non proprietary data from these units will be made available to the public thru integration with the National Geothermal Data System (NGDS). Publically viewable data display screens of the Ormat and UTC ORC units are being planned to showcase the operation and power output of these coproduction systems. Key data analysis to be reported includes system efficiency calculations, base load power offset, and LCOE determination.

NREL will also be involved in implementing system improvements to the Ormat and UTC ORC units to address current challenges faced in the geothermal industry. After NREL installs the instrumentation and data systems are installed, baseline data will be collected and analyzed to evaluate potential system improvements. Hybrid cooling technology evaluation is the target of NREL's modeling and analysis of the Ormat ORC system. NREL is currently evaluating commercially available hybrid cooling systems that can be retrofitted to the Ormat unit to improve its annual power output. NREL is evaluating hybrid cooling technologies by modeling the performance of the Ormat system in Aspen. The modeling is being performed to evaluate the effectiveness of changing the cooling system from an air cooled condenser to a hybrid air/water cooled system. Modifications/improvements to the UTC PureCycle ORC system are also planned, but no specific process modification/system improvement has been down selected. Overall, NREL's future activities will be focused on recording/analyzing data from these geothermal ORC systems to improve their performance and promote the use of these renewable low temperature geothermal energy technologies.

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