The Geysers Geothermal Field, an Injection Success Story

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ABSTRACT

The Geysers Geothermal field, the largest geothermal field in the world, is about 130 km north of San Francisco, California. The field started production in 1960 with a 12 MWe power plant. By 1987, steam production peaked at 112 billion kg, generating approximately 1,500 MWe (installed capacity = 2,043 MWe). A rapid decline in production ensued. At that point the cumulative mass replacement rate (i.e., the fluid re-injection rate) was only about 25%, resulting in reservoir dry-out and superheat. Without additional recharge, only a small percentage of the recoverable heat-energy could be extracted. Hence, with injection, a major heat mining operation could start. However, there was no water except for the cooling tower recoveries and seasonal streams.

For many years, Lake County and the City of Santa Rosa (Sonoma County) had been looking for avenues to dispose of their treated effluent. Since The Geysers was in need of water and the county and city needed an effluent disposal outlet, a unique public-private collaboration began. In 1997, Lake County constructed a 42 km long pipeline to transport 1.01 million kg of secondary treated effluent per month to The Geysers for injection, which resulted in additional steam. This prompted Santa Rosa and other municipalities in Sonoma County to construct a similar pipeline. By the end of 2003, the Santa Rosa pipeline was completed, resulting in an additional 1.25 million kg of tertiary treated effluent to The Geysers every month. The current mass replacement from both pipelines and other sources is about 85% of production. This has resulted in sustained steam production, a decrease in non-condensable gases, improved electric generation efficiency, and lower air emissions. The additional electricity generated as a result of these two pipelines is about 155 MWe per year. The Geysers has become the largest heat mining operation in the world. By December 2009, The Geysers had produced 2,453 billion kg of steam, and injected 997 billion kg of fluids, resulting in a net mass replacement of 40.6%. Locally this success story is called "Flush to Flash."

1. Introduction

The Geysers Geothermal field, which is located (Figure 1) about 130 km north of San Francisco, California, started production in 1960 with a 12 MWe power plant. The field development picked up at a rapid pace from 1979 through 1989. Despite the drilling of new wells and an increase in installed capacity, the total steam production peaked at 112 billion kg in 1987, whereas the average steam production per well peaked in 1972 at 55,439 kg/well/hr (Figure 2). From 1972 through 1989 average well production steadily continued to decline, even though the total steam production was increasing during this time. The reason being many new wells were drilled during this time by several companies resulting in new wells cannibalizing exiting wells flow. After 1989 the total steam produced and average well production seems to be tracking each other, as number of wells did not changed significantly.

Currently The Geysers has 19 active power plants, while seven have been decommissioned. (Figure 1).

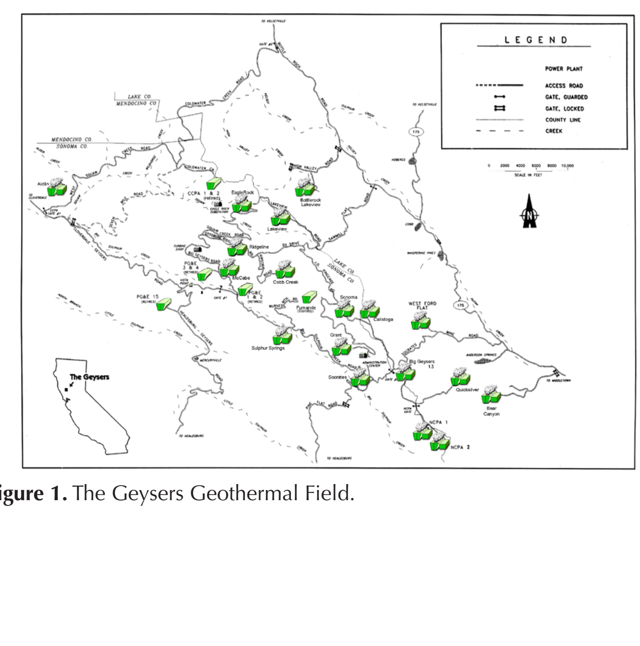

Figure 1. The Geysers Geothermal Field.

Table 1. The Geysers Geothermal Field Summary.

Area	16 x 6 km = 64 sq km	
Wells	460 Steam Wells, 75 Injection Wells	
Average Well Depth	2,500 m	
Average Caprock Depth	1,200 m	
Bottom Hole Temperature	300°C (Initial)	250°C (Current)
Reservoir Pressure	500 psi (Initial)	100 psi (Current)
Cumulative Steam Produced	2.4 trillion kg	
Steam Production (2009)	59 billion kg	
Injection (2009)	42 billion kg	
Electricity Produced (2009)	7.6/6.9 (gross/net) million megawatt hrs	

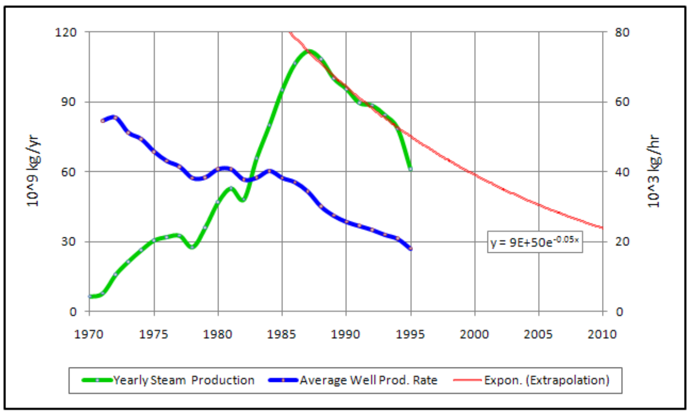

Figure 2. Yearly Field-wide Steam Production and Average Well Production/Month (Source: Division of Oil, Gas and Geothermal Resources).

From 1960 through 1969, the condensate collected from the power plant cooling towers was discharged into Big Sulphur Creek. Thereafter discharge limits set by the Regional Water Quality Control Board (RWQCB) resulted in injection being the most viable disposal method. From 1976 through 1980 the mass replacement rate (i.e., the fluid re-injection rate) was about 25%, which is approximately the cooling tower recovery at The Geysers. By 1980, the philosophy of injection started shifting from "disposal" to "heat mining." Prior established water rights limited the ability of the operators at The Geysers to extract water from the streams and creeks in this region, but from 1980 through 1993 the amount of fresh water extraction that was allowed was able to increase the mass replacement rate to about 28%. As the steam production and reservoir pressures continued to decline, the need to increase mass replacement became increasingly acute. However, there was no more water available at The Geysers; all of the cooling tower recoveries, water available from the streams, and surface water sources were already being re-injected into the reservoir.

2. Southeast Geysers Effluent Pipeline (SEGEP)

At the time The Geysers steam production and reservoir pressures were declining rapidly, the communities of Lake County, City of Santa Rosa, and other municipalities were trying to find solutions for the disposal of their treated sewage waters. Beginning in the early 1990s, Lake County started looking into piping its treated waters into The Geysers. Studies showed that injecting wastewater could achieve two critical objectives at same time: first, a continuous supply of steamfield recharge water that could help mitigate The Geysers productivity decline; and second, an effluent disposal method that would be environmentally superior to conventional surface water discharge methods currently in use. Slowly they built consensus on the project and a partnership was developed between public and private sectors.

After two years of construction, the pipeline was formally dedicated on October 16, 1997. The total construction cost was $45 million, including $37 million for the pipeline and $8 million in wastewater system improvements. The 41-to-51-cm diameter pipeline is 42 km long. It started transporting 883,000 kg of secondary treated effluent per month to The Geysers for injection. The injection project success resulted in a second phase, completed in 2003, which added more sanitation districts. With this extension, the system currently uses eight pump stations to move approximately 1.01 million kg of treated effluent through 85 km of pipeline with a total elevation gain of 600 meters to the injection delivery station in The Geysers. In ten years (August 1997 - August 2007) the Lake County pipeline has brought in 106.6 billion kg of water, generating about 3.5 million MWh of additional electricity.

3. Santa Rosa Recharge Geysers Pipeline (SRGRP)

During the 1970s and 1980s, Santa Rosa and its neighboring communities experienced rapid growth. This growth, combined with increasingly stringent regulations on wastewater and unusual weather conditions, made its wastewater system vulnerable to failure. Responding to some spills and planned discharges, the Regional Water Quality Control Board fined the City and issued a cease-and-desist order. In addition, it required the City to develop a long-term plan that would prevent such releases in the future. After studying many possible solutions, in 1997, the City of Santa Rosa prepared and adopted The Geysers injection alternative. Like the Lake County pipeline, a partnership was developed between public and private sectors. Construction began in 2001 and was complete by September 2003. The 65 km pipeline, 76-to-122-cm in diameter, and three pump stations lift the water 850 m from the valley floor near Healdsburg to the million gallon termination tank at The Geysers. Calpine provides the 8 MWe of electrical power needed to operate the pumps. SRGRP facilities north of the termination tank are owned and operated by Calpine and include 22 km of pipelines (diameter 20-to-76 cm), one pump station, and two tanks. Using an additional one megawatt of power, SRGRP water is distributed around the field, primarily to areas not previously supplied with fresh or SEGEP water.

From November 2003 to August 2007, SRGRP has been delivering 1.25 million kg per month of tertiary treated effluent from Santa Rosa and other municipalities in Sonoma County to The Geysers for injection. In August 2007, the City of Santa Rosa approved an increase in the amount of wastewater pumped to The Geysers by 35%. This will make Santa Rosa one of the few cities in California that recycles 95% of its wastewater.

The SRGRP injection is expected to generate an additional 85 MWe annually. By extending the life of the steamfield, the SRGRP will help ensure that the environmental benefits of geothermal power generation will continue into the future.

4. Pressure and Steam Decline

The combined additional mass replacement as a result of the two pipelines has had a positive effect on steam production and reservoir pressure maintenance. In Figure 2, monthly steam production is plotted against time. The green line denotes the actual production; the red line is the exponential decline curve-fit. An attempt is made to provide some ballpark values using published data and some approximate decline curve estimations. As is the case with any decline curve method, the expected results may change, not only due to individual interpretation, but also if the reservoir parameters are changed. By using this method, the annual steam production decline rate decreased from 5% per year before the pipeline injection to less than 1% (Figure 3). There is a un-explained production drop in 2009.

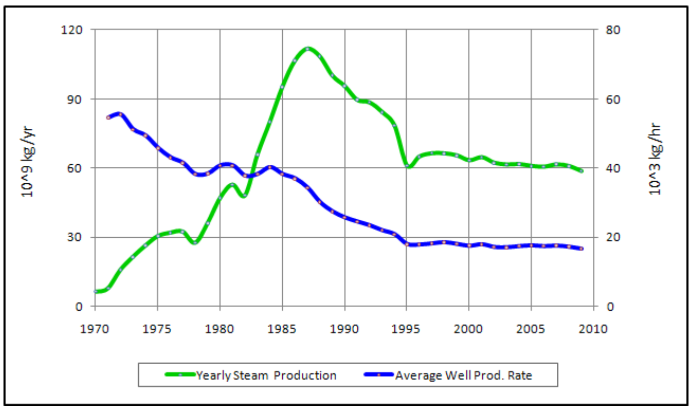

Figure 3. Yearly Field-wide Steam Production and Average Well Production/Month. The annual steam production decline rate decreased from 5% per year (1987-1994) before the pipeline injection to less than 1% (1996-2008).

5. Current Status

The current mass replacement from both pipelines and other sources varies from year to year between 80% and 90% of production, whereas on a monthly basis the mass replacement can reach 120%. This has resulted in significant additional steam production, decreases in the concentration of non-condensable gases in the steam being produced, improved electric generation efficiency, and lower air emissions. The Geysers has become the largest heat mining operation in the world. By the end of December 2009, The Geysers had produced 2,453 billion kg of steam, and injected 997 billion kg of fluids, resulting in a lifetime net mass replacement of 40.6% (Figure 4). Even with the anticipated increases in future annual mass replacement rates, which are expected to be more than 100% of production, the cumulative mass replacement will seemingly never be able to approach 100%.

6. Non Condensable Gases (NCG)

As noted, supplemental injection in The Geysers supports reservoir steam pressure, thus decreasing the rate of production

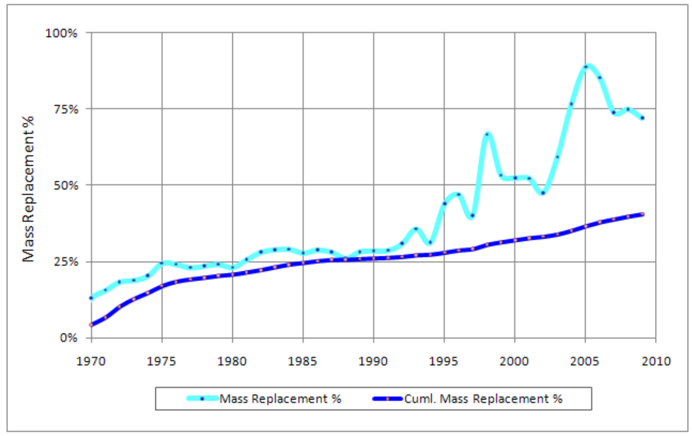

Figure 4. Filed-wide yearly and cumulative mass.

decline. An additional benefit of supplemented Geysers injection has been the decrease of Non Condensable Gases (NCG) in produced-steam. Field-wide NCG concentrations have been increasing with the depletion of the steam and with the re-injection of produced-steam condensate. The injection of treated effluent, which contains very little dissolved NCG, is resulting in the formation of low NCG injection-derived steam that dilutes the NCG concentrations in the reservoir. Lower levels of NCG in produced steam have resulted in lower air emissions and more efficient steam-to-electric generation. For example, between 1986 and 2003, NCG concentrations in well DX85 increased by over a factor of five (Figure 5). Injection into DX19, which began in late 2003, has reduced DX85 NCG to a level not seen since 1990 (Beall, et al., GRC, 2007).

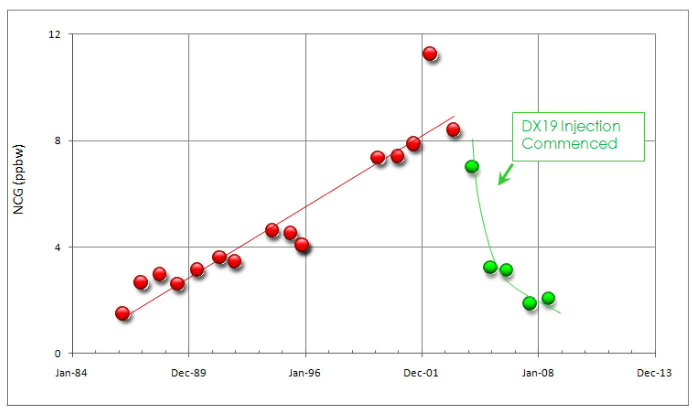

Figure 5. NCGs concentration versus time in well DX85 (Beall, et al., GRC, 2007).

7. Injection Methods

A typical injection well will have a cemented casing string up to the base of the cap rock, at approximately 4,000 feet. All casings in geothermal wells in California are required to be continuously cemented from the casing shoe to the surface. From the base of the cap rock to the total depth of approximately 9,000 feet, a slotted liner may be hung to deliver the injection fluids to targeted parts of the reservoir. The initial reservoir pressure was about 500 psi, while the current reservoir pressure is about 100 psi. At 4,000 feet, net hydrostatic pressure of the injection column will be about 1582 psi. With this kind of pressure differential and very high fracture permeabilities, (hundreds of milli darcies) large amounts of injection fluids can be easily gravity fed into the reservoir. Currently, there are 75 injection wells in The Geysers, most of them converted from production wells.

8. Induced Seismicity

With the geothermal production and injection activity at The Geysers, induced seismicity became a concern. The Geysers field is continuously monitored by three seismic arrays operated by the United States Geological Survey (USGS), Lawrence Berkeley National Laboratory (LBNL), and Calpine (Calpine array ceased in 2007). Two strong motion detectors have also been installed in the southeastern part of The Geysers. The seismicity data may be downloaded, almost in real time, from the USGS and LBNL websites. In most oil and gas operations, the induced seismicity is caused by the stresses related to the significant pressure drawdown from the oil and gas production. However, at The Geysers the induced seismicity, for the most part, is directly proportional related to injection, which results in the stresses produced by rock being rapidly cooled. Seismically, The Geysers is very active and about one thousand seismic events of magnitude 1.5 and greater are recorded annually. Only a few of these are large enough to be felt, with the largest magnitude recorded being 4.5. The number of seismic events seems to be directly proportional to the amount of injection (Figure 6). However, the number of earthquakes magnitude 3.0 and higher seems to occur at the same rate from year to year.

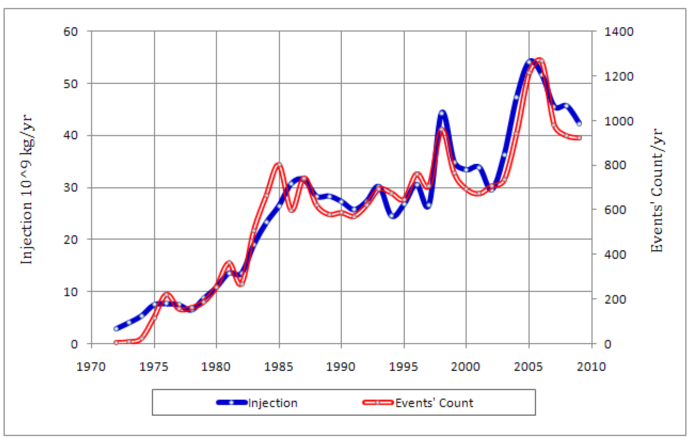

Figure 6. Number of seismic events (>=1.5) and injection.

9. Conclusion

With 49 years of production and injection history, and including 460 production and 75 injection wells, the Geysers today provides 25% of all of California's renewable electrical energy. Treated effluent injection from the two pipelines amounts to about two-thirds of the total injection. This results in about 135 MWe of additional electricity annually, extending the life of the field and providing a better alternate for disposing the local communities' wastewater. Micro-seismicity is increasing with the increased injection, but larger seismic events seem to be unrelated to injection.

10. Acknowledgments

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