The Geysers Geothermal Field, an Injection Success Story

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Biography

M. Ali Khan is a Geothermal District Engineer for the State of California, Department of Conservation, Division of Oil, Gas, and Geothermal Resources (DOGGR). In this capacity, he oversees geothermal drilling, production and injection operations and promotes public health and safety through public meetings and dissemination of technical data. Khan earned BS and MS degrees from the Middle East Technical University, Ankara, Turkey. For 30 years Khan has worked in upstream oil, gas, and geothermal projects in Turkey, Pakistan, Germany, and the United States. Khan received the American Association of Petroleum Geologists' Gulf Coast Section's "Best Paper" and "Levorson" awards for "New Ideas in Exploration of Oil and Gas," as well as the Department of Conservation's "Superior Accomplishment Award."

Abstract

The Geysers Geothermal field, the largest geothermal field in the world, is about 100 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. 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. In The Geysers, most of the heat is thought to be stored in the rock matrix as compared to pore liquids in the reservoir. 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 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 135 MWe per year. The Geysers has become the largest heat mining operation in the world. By August 2007, The Geysers had produced 2,312 billion kg of steam, and injected 884 billion kg of fluids, resulting in a net mass replacement of 38%. Locally this success story is called "Flush to Flash."

Introduction

The Geysers Geothermal field, which is located about 100 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 1).

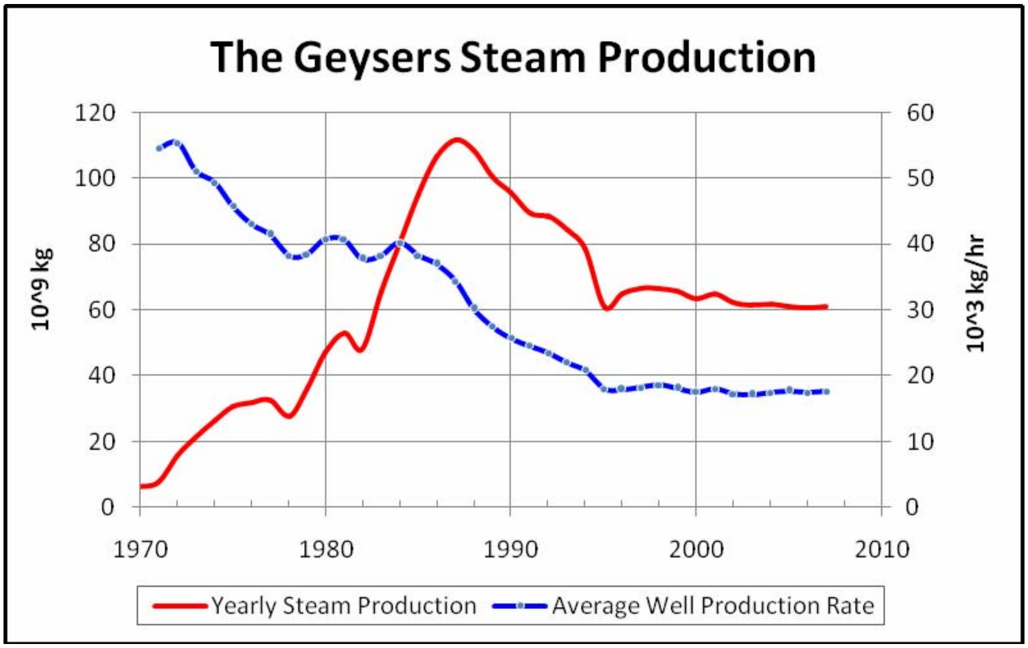

Figure 1. Steam Production (Division of Oil, Gas, and Geothermal Resources).

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." From 1980 through 1993, streams and creeks were tapped, thereby increasing the mass replacement rate to about 28%. As the steam production and reservoir pressures declined, the need to increase mass replacement became more acute. However, there was no more water available at The Geysers; all the cooling tower recoveries and streams, creeks and springs were already being re-injected into the reservoir.

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 their treated sewage waters. From 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, as a continuous supply of steamfield recharge water that could help mitigate The Geysers productivity decline; and second, as 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 about 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 additional electricity (Figure 2).

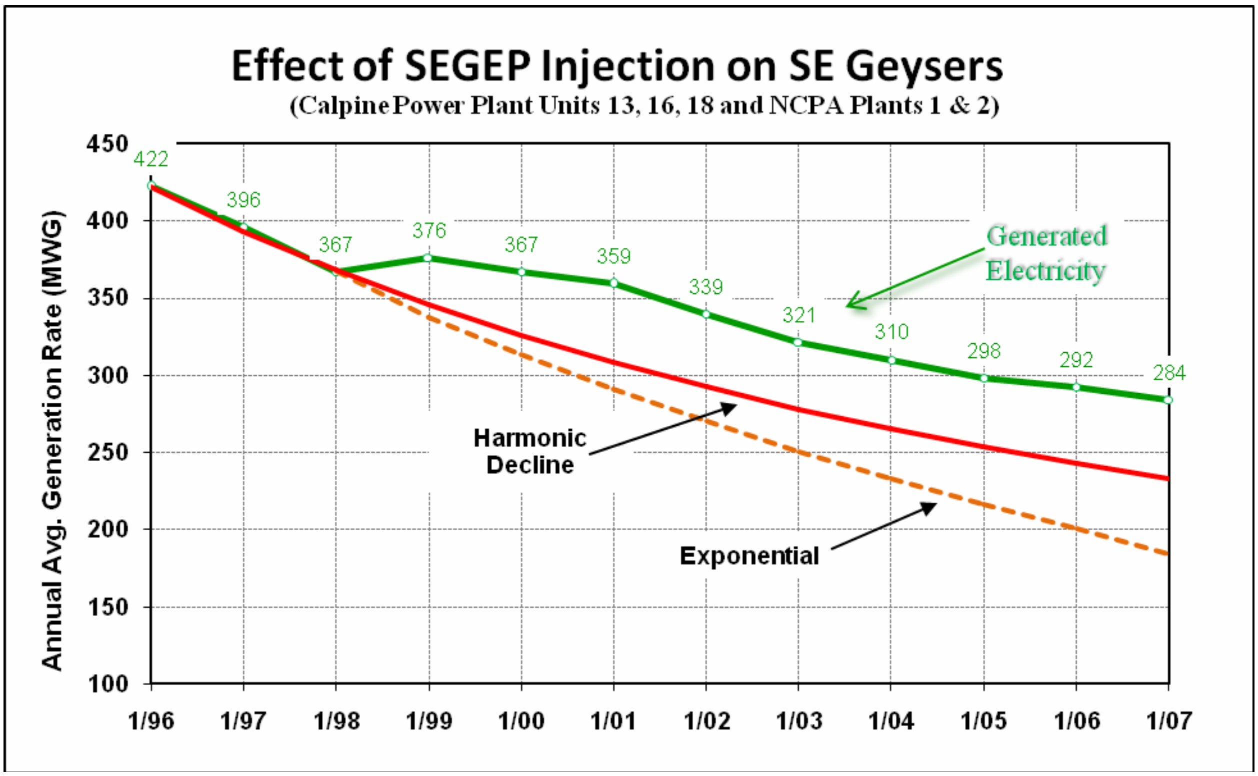

Figure 2: Effect of SEGEP Injection on SE Geysers (Courtesy of Calpine and NCPA).

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 RWQCB fined the City and issued a cease-and-desist order. In addition, it required the City to develop a long-term project 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. 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 to increase the amount of wastewater pumped to The Geysers by 35%. This will make Santa Rosa one of the few cities in California that recycle 95% of its wastewater.

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

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 be as high as 120%. This has resulted in a sustained increase in steam production, decrease in non-condensable gases, improved electric generation efficiency, and lower air emissions. The Geysers has become the largest heat mining operation in the world. By the end of August 2007, The Geysers had produced 2,312 billion kg of steam (Figure 3), and injected 884 billion kg of fluids, resulting in a lifetime net mass replacement of 38%. The Geysers anticipated future yearly mass replacement rates running lower than 100%, we may never reach 100% cumulative mass replacement.

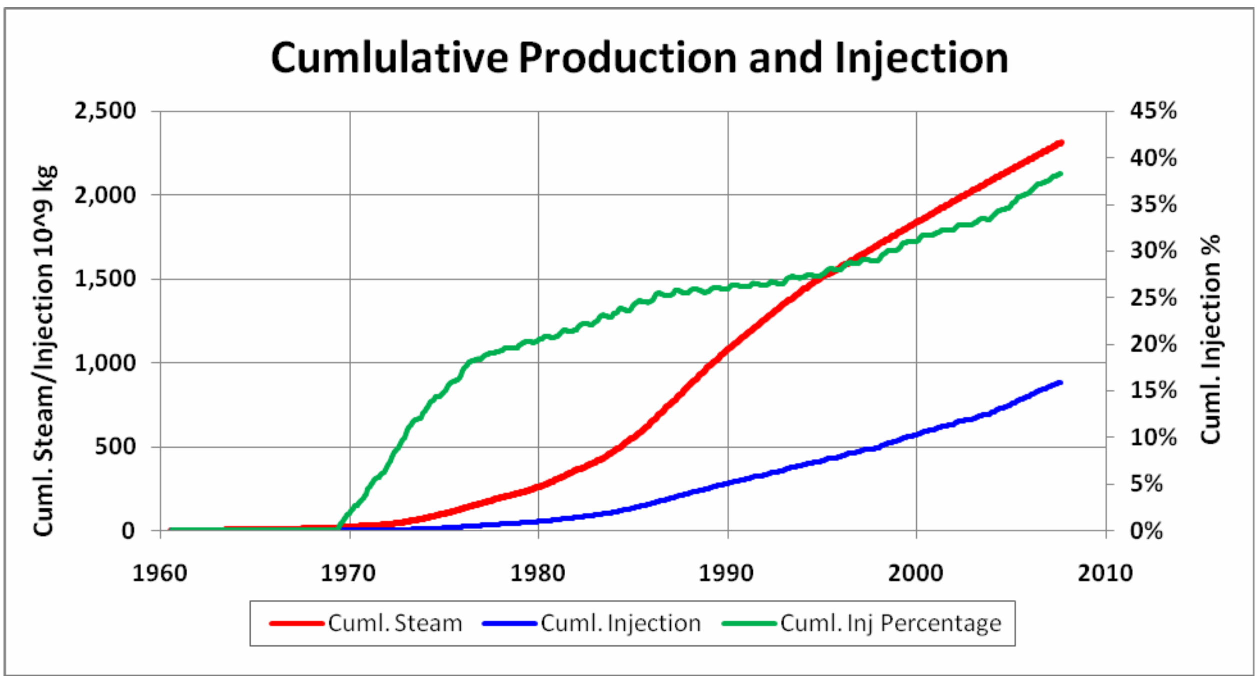

Figure 3: Cumulative Production and Injection (Division of Oil, Gas, and Geothermal Resources).

Pressure and Steam Decline

The combined additional mass replacement as a result of the two pipelines had a positive effect on the steam production and reservoir pressure maintenance. In Figure 4, annual steam production is plotted against time. The red line denotes the actual production, the blue line is the semi-log decline curve-fit, and the green line is exponential 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 12% before the pipeline injection to less than 1%.

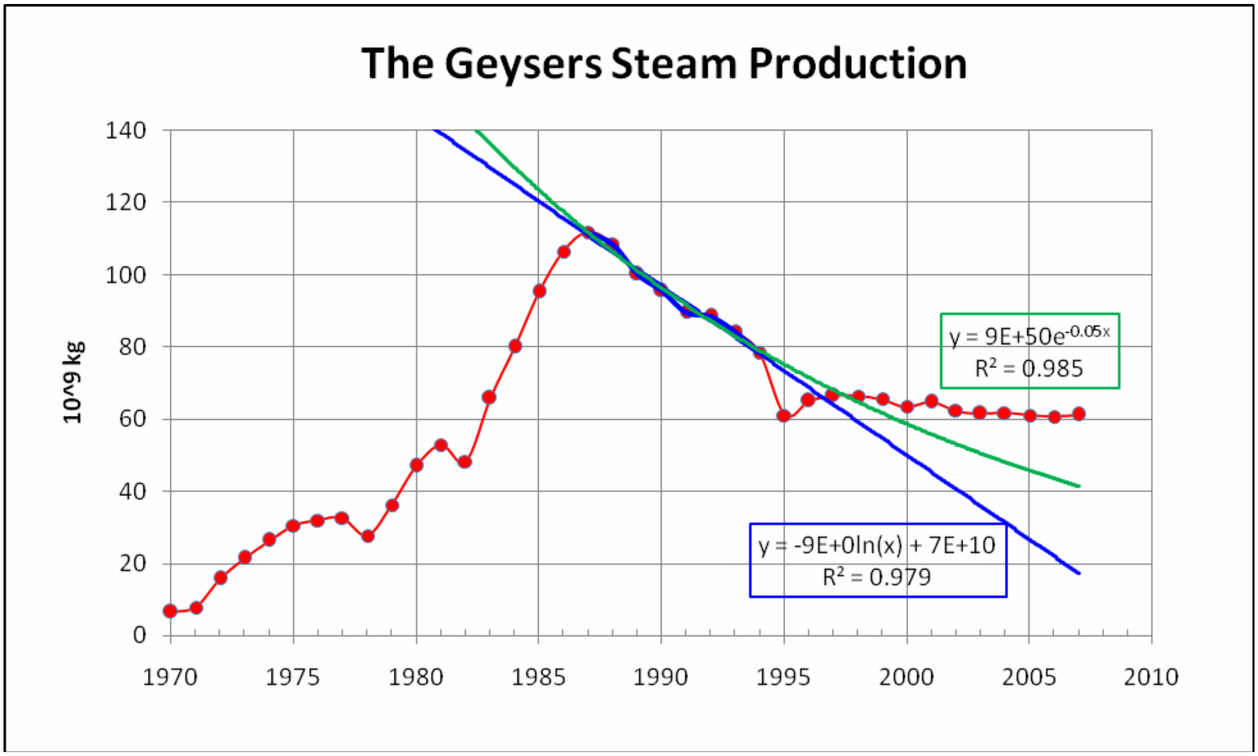

Figure 4. Steam production and decline curve-fit.

Non Condensable Gases (NCG)

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

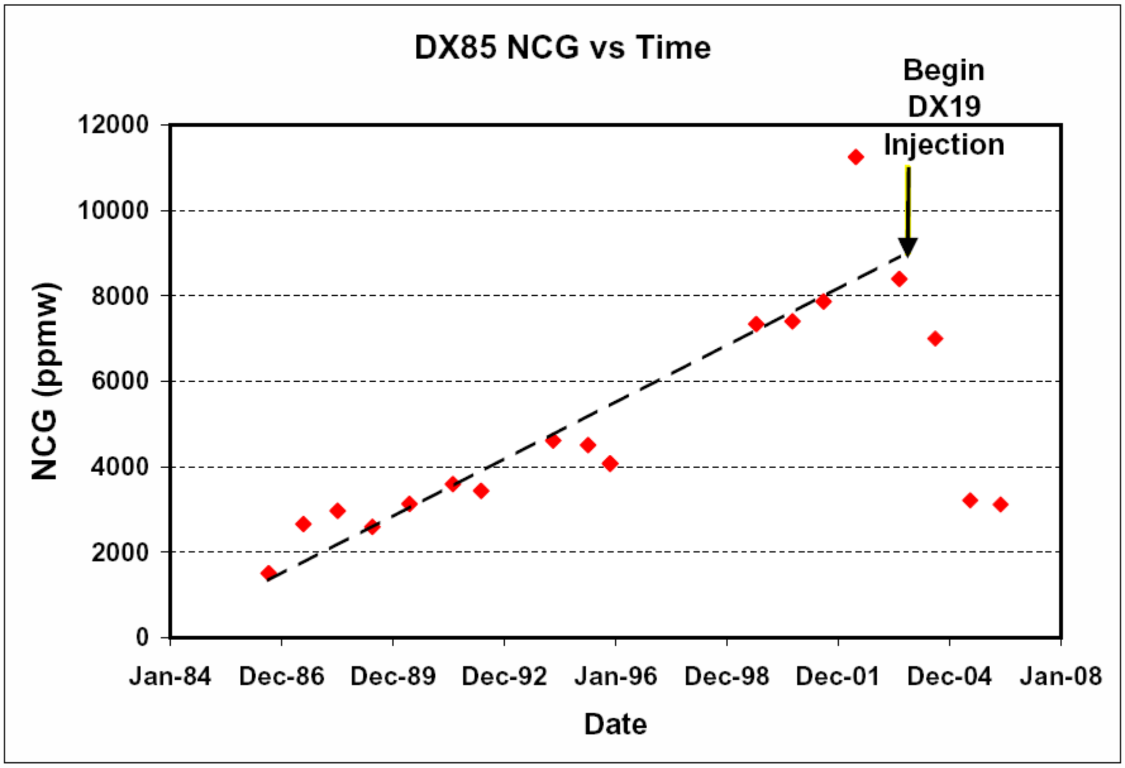

Figure 5. DX85 NCG concentration versus time (Beall, et al. in press).

Injection Methods

In Figure 6, a typical injection well diagram is presented. A typical well will have a cemented casing string up to the base of cap rock, at approximately 4,000 feet. All casings in geothermal wells in California are requited 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 500 psi, while the current reservoir pressure is about 150 psi. At 4,000 feet, net hydrostatic pressure of the injection column will be about 1582 psi (1732-150). 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. Currently, there are 75 injection wells in The Geysers, most of them converted from production wells. Two nearly horizontal injection wells have been drilled in The Geysers. The horizontal wells were intended to spread injection fluids over a wider areal extent, and thereby reduce the injection induced micro-seismicity. At this time, the result seems to be encouraging, but it maybe too early to make a definite conclusion.

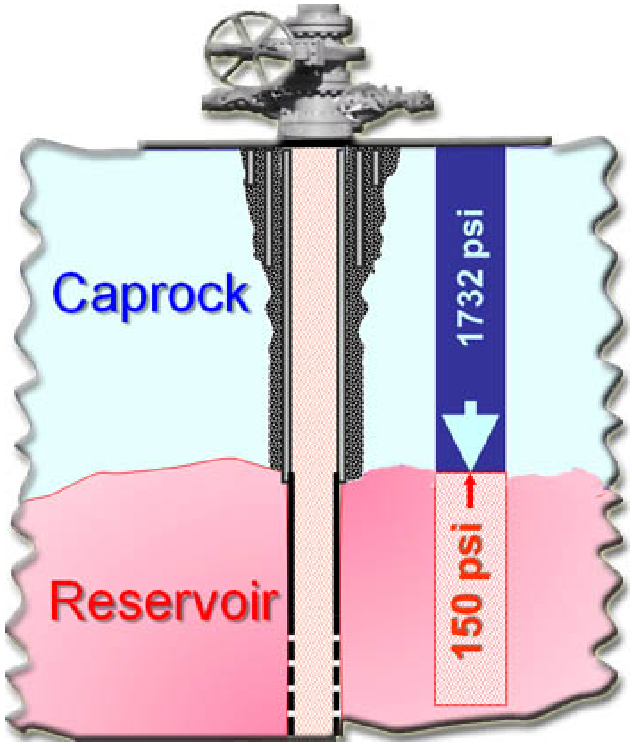

Figure 6. A typical injection well schematic.

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. Two strong motion detectors have also been installed in the southeastern part of The Geysers. These data may be downloaded, almost in real time, from the USGS website. In most oil and gas operations, the induced seismicity is related to the production and stress related to the significant pressure drawdown. However, at The Geysers the induced seismicity, for the most part, is related to injection, which results in the stresses produced by rock being rapidly cooled. Seismically, The Geysers is very active and thousands of micro-earthquakes (MEQ = magnitude<3) are recorded annually. Only a few of these are large enough to be felt, with the largest magnitude being 4.6. The number of MEQs seems to be increasing with the additional SEGEP and SRGRP injection. However, the larger earthquakes (M>=3.0) seem to be about the same from year to year.

Conclusion

The Geysers in 47 years of production and injection, with 460 production and 75 injection wells, is providing 25% of all California's renewable electrical energy. The treated effluent injection from the two pipelines amounts to about two-thirds of the total injection. This results in about 155 MWe of additional electricity, 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.