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OVERVIEW OF EXTRACTION OF MINERAL/METALS WITH THE HELP OF GEOTHERMAL FLUID

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ABSTRACT

Economic production of minerals, along with production of electric power from geothermal power plants, can be termed as a cascade use of geothermal power plants. Minerals, such as silica, lithium, manganese, zinc and sulfur, can be extracted from geothermal fluid to obtain marketable byproducts. These minerals are also a major source of corrosion and scaling, which often leads to mechanical failures. Methods of metal extraction developed previously and their importance for power plants to operate efficiently will be discussed here.

INTRODUCTION

Geothermal energy is defined as energy stored inside the earth's crust in the form of a high temperature heat source. Because of the magma or high heat flow, rock close to it gets heated and we get molten rocks containing minerals. This molten rock interacts with rain water which percolates through major faults and fractures resulting in the formation of dilute brine. Geothermal fluids interact with the host rocks and tend to become increasingly saturated with various minerals. Some geofluids are rich in minerals while some are free of minerals. A geothermal fluid consists of water, steam or combination of the two. Geofluids are generally hot and salty (because of the mineral content). Any of these fluids can act as a carrier to transfer geothermal energy from the subsurface, up through wells and to the surface. The resulting chemical compositions of geofluids are determined by the composition of the rocks, chemical composition of the fluid, and the temperature and pressure during the fluid and rock mass interaction. Due to the large availability of geothermal resources in Nevada and California, geofluid can be used for the extraction of water soluble minerals as well as precious metals.

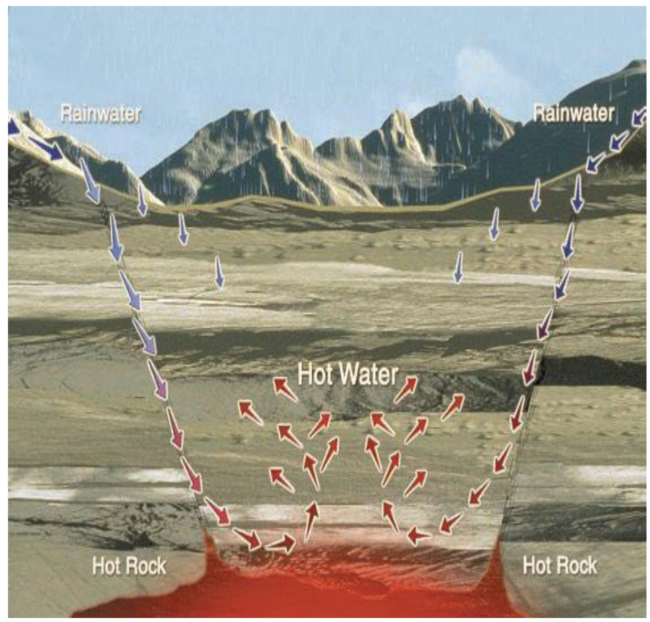

Figure1: Percolation of rain water into fractures and reheating dueto interaction withhot rocks (GEO, 2000)

A great number of these geothermal resources can be increased if we can extract more energy from lower temperature reservoirs. New technologies are introduced that will help to extract more and more energy from the earth. New technologies such as Enhance Geothermal System (EGS) may help to extract more heat from areas where there is less availability of underground water and permeability.
Geothermal fluids are considered in the range of 200°F (93°C) to 400°F (204°C) for generation of hydrothermal electricity (Kagel, 2008).

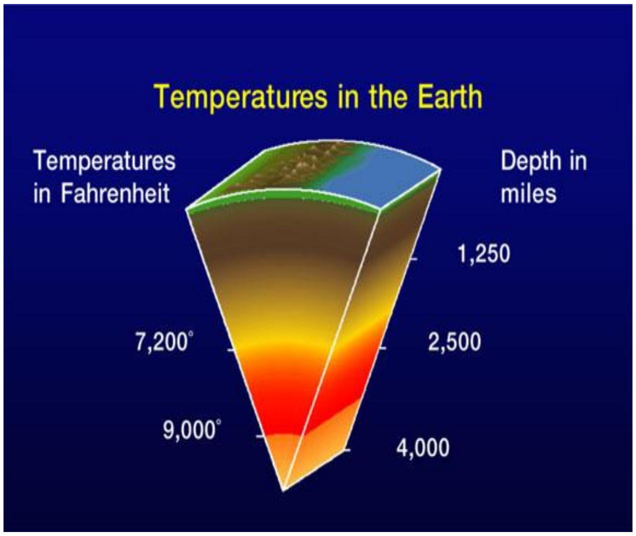

Figure 2: Temperature of earth crust (GEO, 2000)

Due to fault formation and other geologic reasons, subsurface temperatures of Nevada and California are very high. These regions are also rich in soluble minerals. When such minerals are subjected to high pressure and temperature, minerals become soluble resulting in fluid with constituent from soluble minerals.

GEOTHERMAL AND MINING INDUSTRY

Geothermal fluids interact with the host rocks and tend to become increasingly saturated with various minerals. Some geothermal fluids can be rich in minerals while some are relatively dilute.

The resulting chemical compositions of geo-fluids are determined by:

- Composition of rocks
- Chemical composition of fluid.
- Temperature and pressure during the fluid and rockmass interaction.

NaCl, $NaSO_4$ and $Na/CaCO_3$ are some of the major geothermal fluids that are identified in Nevada (Trexler., et al 1990)

Due to large availability of geothermal resources in Nevada and California, with varying concentration of metals/minerals, geofluid can be used for the extraction of water soluble minerals as well as precious metals.

For example:-

1. The use of geothermal fluid in heap leaching for Silver and Gold extraction in Round Mountain Gold and the Florida Canyon Mine. (Trexler., et al 1990)
2. Extraction of silica from geothermal power plant in Mammoth Lake, California. (Parker A., 2005).
3. Mining lithium, from geothermal fluid, in Salton Sea hypersaline geothermal reservoir in Imperial Valley, CA.
4. Collection of sulfur from geothermal steam (Li et al., 1978).

Table 1. Examples of mineral composition of few geothermal fields in NV and CA (Bouncier et al, 2003 and Gallup, 1998)

	Salton sea, CA	Coso, CA	Dixie Valley, NV	Mammoth Lake, CA
Temp., (°C)	296	274	246	165
Silica, (mg/kg)	>461	>711	>599	~ 250
Boron, (mg/kg)	257	119	9.9	NA
Lithium, (mg/kg)	194-230	45	2-4	NA
Zinc, (mg/kg)	438	0.03	NA	NA

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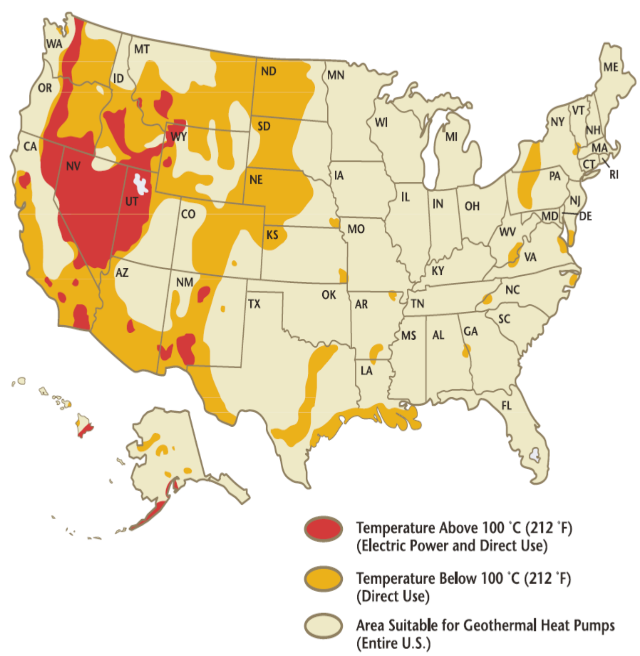

Figure 3: Temperature distribution throughout the USA for use of geothermal (Green and Nix, 2006)

EXTRACTION OF GOLD AND SILVER USING HEAP LEACHING WITH THE HELP OF GEOTHERMAL FLUID

Heap leaching is an industrial process that is used to extract precious metals such as gold and silver. It is conducted at approximately 120 mines worldwide (Kappes D., 2002). The main advantage of heap leaching is low capital cost compared to other extraction processes. Around 12% of the gold is extracted with the help of this process. Nevada is known as the birthplace of the heap leaching process. Modern day leaching was started in Nevada in 1960 (Kappes D., 2002). Figure 4 shows the schematic diagram of the thermally enhanced heap leach process.

Heap leaching may be defined as stacking of metal-bearing ore into a "heap" on an impermeable pad, irrigating the ore for an extended period of time with a chemical solution to dissolve the sought-after metals, and collecting the leachant ("pregnant solution") as it percolates out from the base of the heap(Kappes D.,2002)

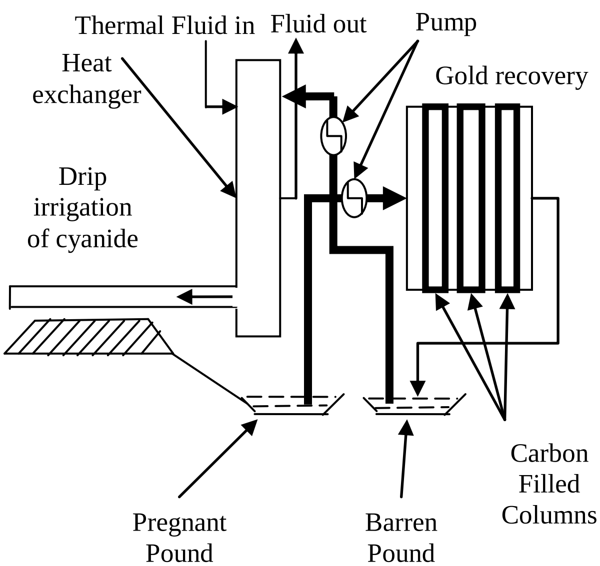

Figure 4: Idealized thermally enhanced heap leach (Trexler., et al 1990)

Pregnant solution is pumped through activated charcoal at the process plant, which absorbs gold and silver. Cyanide solution is pumped to a holding basin, where lime and cyanide are added to repeat the leaching process. Gold bearing charcoal is chemically treated to release the gold and is reactivated by heating for future use. The resultant gold bearing strip solution, more concentrated than the original pregnant cyanide solution, is treated at the process plant to produce bars of impure gold. The gold is sold or shipped to a smelter for refining.

Geothermal fluid can be used for direct heating or indirect heating. During indirect heating, the pipe carrying hot fluid can be laid throughout the heap leach pad to keep the heap leach pad warm and enhance the chemical processes by providing a higher temperature for the reaction. In case of direct heating, geothermal fluid is directly circulated through the leach pad to get the same results as that of indirect heating. During direct use of the geofluid, some difficulties related to chemistry may arise because of the chemical composition of geofluid resulting in an undesirable reaction. Geofluid may contain some metals and non-metals that have the ability to react with cyanide, which is a major chemical component in heap leaching process. Non- precious metals and non-metals, which may react with cyanide to create precipitate and disturb the chemical process by plugging the cyanide dripping through leach pad, are called cynocide (Bloomquist, 2006). Usually cynocides do not stall the leaching process.

Advantage of use of geofluid in heap leaching

Due to the heating of the heap, the speed of the chemical recovery of the precious metal is improved. Also because of the temperature enhancement, a mine operator can operate a leaching pad throughout the year. This advantage will help the mine operator to generate more revenues and will give year round employment opportunities. Heating of cyanide solution will help to enhance gold and silver recovery by 5 to 7 % depending on the temperature of the geofluid (Bloomquist, 2006).

EXTRACTION OF SILICA FROM GEOTHERMAL POWER PLANT

Extraction of silica from geothermal fluid is termed as the cascade use of geothermal energy. Geothermal fluid contains silica which clogs tanks, pipes and other equipment as the pressure and temperature decreases during processing. So, by removing silica from the geothermal fluid, the geothermal industry will provide silica, which is a marketable by-product. Also, it will increase the hot fluid extraction from production wells. This experiment is carried out in Livermore's mobile laboratory at the Mammoth Pacific LP geothermal power plant in Mammoth Lakes, California. The Livermore extraction process involves running a geothermal fluid through a reverse-osmosis separation process to create freshwater and concentrated brine. The freshwater is used for evaporative cooling, and the concentrated brine is pumped into a reactor where chemicals are added and silica is extracted. The silica-free brine can then be pumped through another process for extraction of other metals before the fluid is pumped to a surface pond and re-injected into the subsurface.

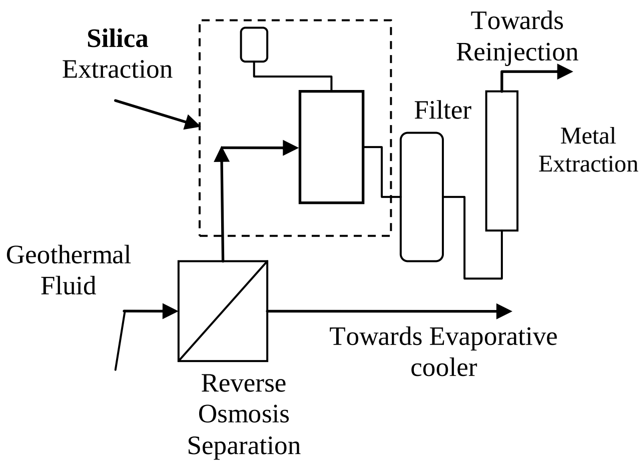

Figure 5: Extraction of silica from geothermal fluid (Parker, 2005)

Chemical reaction of silica separation is given as follows.

$$\mathbf{H_4SiO_4} \rightarrow \mathbf{2H_2O} + \mathbf{SiO_2}$$

(Dissolved Silica) (Quartz siliceous sinter)

Metals like lithium, manganese and zinc can be extracted from geothermal fluid. Figure 5 shows a schematic diagram of the system that extracts silica from geofluid.

Silica production from two similar 50 MWe power plants, located in Salton Sea, CA and Coso, CA, could provide \$10.2 and \$12.9 million per year respectively. These values were calculated assuming a 60% silica recovery rate, a selling price of \$ 2200 per metric ton and a plant capacity of 95 % (Bloomquist G.R., 2006).

Removal of silica from geothermal fluid enhances the performance by reducing the maintenance cost associated with scaling in surface facilities and injection wells (Figure 6). Also, it facilitates the co-production of marketable minerals.

Figure 6 : Scaling in Geothermal pipeline (Bloomquist, 2006)

MAJOR ENGINEERING CHALLENGES DUE TO THE SCALING

Temperature, pressure, chemistry and content of non-condensable gases in geofluid influence the power plant operation and may affect the mechanical, volumetric and thermal efficiencies of the power plant. This will affect power production and cost per kWhr. Any kind of extraneous material that appears on the inner surface of the pipe that carries a fluid is called fouling. Fouling reduces heat transfer and flow through a pipe. This affects mechanical, volumetric and thermal efficiency of the geothermal power plant. This extraneous material may react with the pipe to cause corrosion. To avoid fouling, the following remedies can be used

- Use of fins on inner surface of the pipe
- Use of copper-nickel alloys to reduce corrosion. Carbon steel can be used at low cost to reduce corrosion (Kagel, 2008).
- And flow rate should be managed in such way to limit accumulation on the inner surface of pipes. Figure 7 shows the scaled and corroded tubes from Hoch Geothermal Facility.

Figure 7: Corrosion of tubes (Kagel A., 2008).

Reduction in fouling will help to reduce corrosion and more minerals can be extracted on the surface in a managed manner.

EXTRACTION OF LITHIUM FROM A GEOTHERMAL POWER PLANT

Because of the boost in silica extraction from the geofluid, the extraction of lithium will also be advantageous to the economic viability of a project. Figure 8 shows the lithium extraction schematic diagram. In this process, fluid is extracted from the production well and steam and brine are separated. The steam is then used and the electricity generated. Steam is cooled and reused to mix with waste brine; which is sent to Lithium Extraction Plant. After lithium extraction, water is re-injected into injection wells. In this process, zinc and manganese can also be recovered along with lithium.

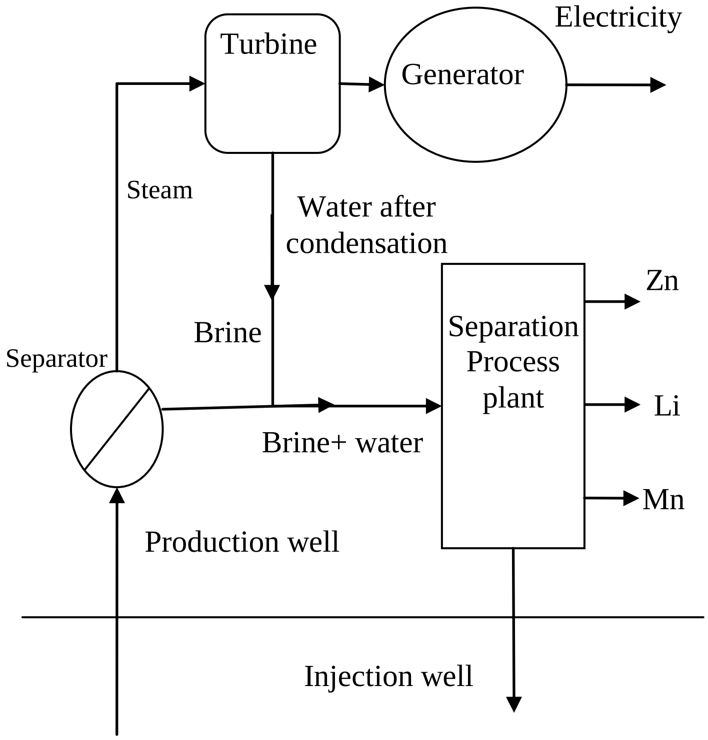

Figure 8: Lithium extraction with Geothermal Fluid (Harrison, 2010)

COLLECTION OF SULFUR FROM GEOTHERMAL STEAM

Geothermal steam contains contaminants such as CO_2, H_2, H_2S, NH_3, CH_4 and N_2. Most of these gases are not only environmentally objectionable, but also they accelerate corrosion of power generating parts, which gives rise to issues like safety and increase in maintenance cost. Figure 9 shows the corroded steam vent at old cove fort power plant.

Figure 9: Corroded Steam Vent (Kagel A., 2008)

Steam containing hydrogen sulfide is purified and sulfur is recovered by passing the steam through a reactor packed with activated carbon in the presence of a stoichiometric amount of oxygen that oxidizes the hydrogen sulfide to element sulfur that is adsorbed on the bed. The carbon can be recycled after the sulfur has been recovered by vacuum distillation, inert gas entrainment or solvent extraction. This process of purifying geothermal steam is very suitable if steam contains some other non-condensable gases.

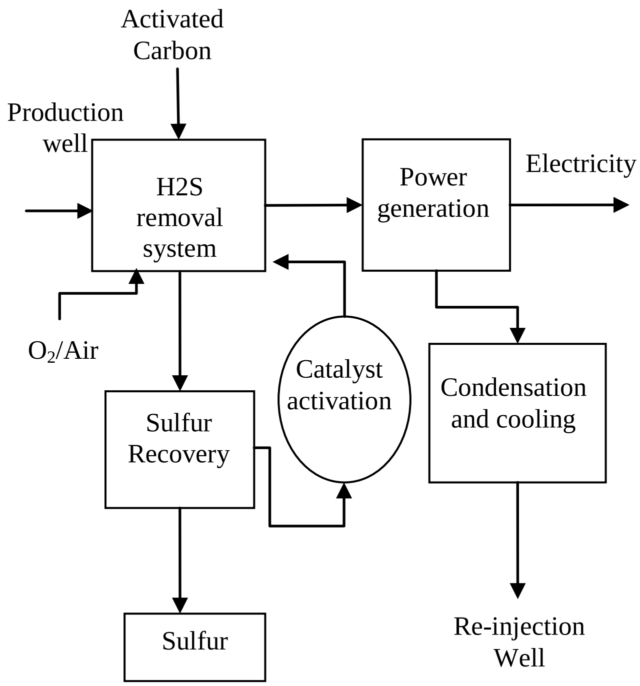

Figure 10: General Flow Diagram of the Catalytic Oxidation Process for H_2S Removal from Geothermal Steam (Li and Brouns, 1978)

CONCLUSION

Geothermal is a clean source of energy. It helps power industries to generate electricity as well as reduce carbon emissions. The ability to remove silica from geothermal fluid can add to energy extraction, reduces operation and maintenance costs. Recovery of silicon opens the way for the recovery of other metals like zinc, lithium, manganese, cesium, rubidium and even precious metals like gold, silver that could increase the probability of the operation.

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