# Introduction

Geothermal fluids interact with the host rock becoming increasingly saturated with various minerals.

The resulting chemical composition is determined by:

- Origin of the fluids
- Lithology of the rocks
- Chemistry of the fluids
- Impacts of such things as boiling

*Table 1.*

# Examples of Mineral Composition at Selected Geothermal Fields

| Item | Salton Sea | Coso | Wairakei | Mammoth Lakes |
|---|---|---|---|---|
| Temperature | 296°C | 274°C | 260°C | 165°C |
| Silica, mg/kg | > 461 | > 711 | > 670 | ca 250 |
| Boron, mg/kg | 257 | 119 | < 0.01 | n/a |
| Lithium, mg/kg | 194-230 | 45 | 13.2 | n/a |
| Zinc, mg/kg | 438 | 0.03 | n/a | n/a |

High concentrations of minerals has often been considered a major nuisance creating:

- Major engineering challenges
- Sever corrosion
- Scaling

# Double Flash plant 10 MWe

# Scaling problems

# Salton Sea 10 MWe

## Half chemical plant – Half geothermal power plant

# Crystal clarifier / pH modification

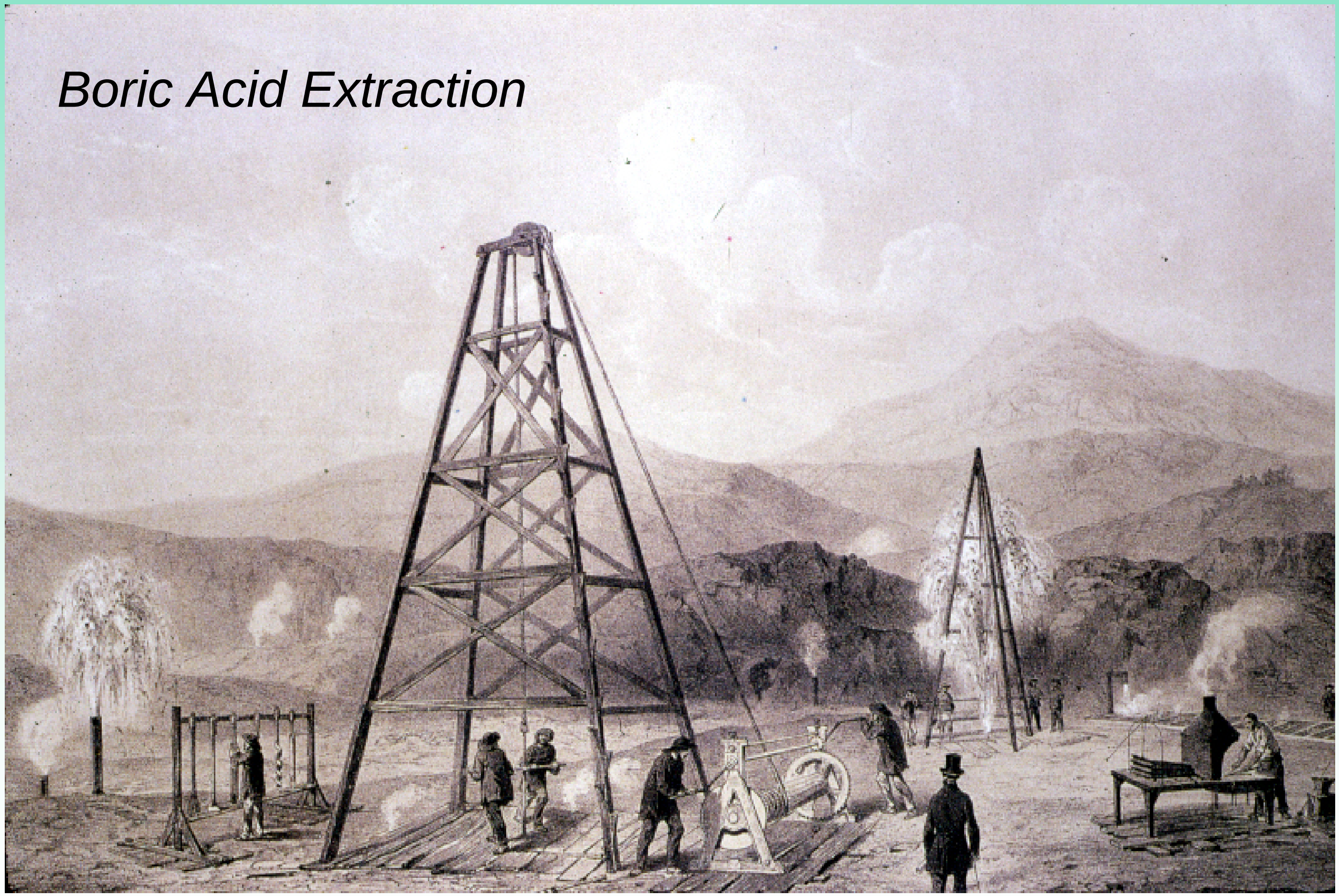
Such problems are not only in the plant itself, but also in injection wells were precipitated minerals can quickly lead to increased injection pressures and eventually the need to work over the wells or drill additional injection wells.

However, one person’s problem is often another’s treasure

# Mining of Geothermal Fluids

Recovery of minerals and metals – “solution mining by nature” – followed by application of established or new hydro-metallurgical techniques for isolation and purification.

The first application of such “mining” techniques took place at turn of the last century in Larderello, Italy.



Some geothermal fields are significantly rich in mineral to be potentially economically viable, among these are:

- Salton Sea, Brawly and Niland

  in the United States
- Milos in Greece
- Assal in Djibouti
- Cheleken in Russia

For example, a 50MWe geothermal power plant could have as much as 35,000 $m^3$ of brine pass through the facility daily.

At a concentration of only 1 mg/kg approximately 30 kg of metal passes through the facility each day.

Minerals and precious metals of primary interest include:

- Silica
- Zinc
- Lithium
- Manganese
- Rare Earths

- Silver
- Gold
- Palladium
- Platinum

## Silica Recovery

Silica is one of the most common and ubiquitous components of geothermal fluids.

It is also one of the most significant problems and potentially one of the most valuable minerals.

A number of processes cause silica to become increasingly supersaturated in the geothermal brine as a result of power production or direct use application, these include:

- Energy extraction/heat extraction
- Water extraction as steam
- pH changes as gases are released

All these processes cause the silica to become increasingly supersaturated, eventually precipitating and forming scale on various plant components or in injection wells.

Because the degree of precipitation increases with decreasing temperature of the brine, it often is the limiting factor in determining how much energy can actually be extracted.

In the Wairakei geothermal field in New Zealand, 130°C is the lower limit for energy extraction because silica scaling becomes too difficult to control.

If the temperature could be reduced from 130°C to 90°C over 1MWe could be produced from approximately every 60 liters per second of brine flow.

For example, silica scale also interferes with the extraction of:

- Lithium
- Manganese
- Zinc
- Etc.

Thus the key to both additional power generation and mineral co-production of minerals is to minimize silica interference.

Silica can be removed by forced precipitation as a high surface area porous material with properties similar to those of commercially produced silica making it a very marketable product.

The world-wide demand for silica is over 3 million kilograms of commercial grade silica per day

Specific uses include:

- Desiccants and anti-caking agents in human and animal food.
- Abrasives in sandpaper and for use in silicon wafer-polishing.
- Filler in plastics, paper, paint and rubber tires.
- Fiber optics and catalyst manufacture.
- Feed stock for making semiconductor silicon, fine chemicals, and chromatographic silica.

Current market is 190,000 tons/year of precipitated silica and 68,000 tons/year for colloidal silica with a 4% annual rate of increase in demand.

Price varies considerably, from $140/ton to nearly $6,600/ton:

- $1.00/kg for use in production of rubber for tires, dental products and pesticides
- $2.00 to $4.00 for use in paint
- $6.00/kg for chromatographic grade silica
- As high as $7.00/gram for high-pressure liquid chromatographic application

Potential revenue:
Silica production from a 50 MWe Salton Sea power plant could provide $10.2 million per year.

The 50 MWe Coso power plant could produce $12.9 million per year in silica.

## Other Metals

Primary interest has been in :

- Lithium
- Manganese
- Zinc

Also of interest:

- Cesium
- Rubidium

# Lithium

Current market is approximately $350 million dollars for use in:

- Ceramics
- Glass
- Aluminum
- Rechargeable lithium batteries

Total U. S. consumption is 2,800 metric tons per year.

Single 50 MWe in Salton Sea area could produce in excess of 3,400 metric tons per year at 95% capacity factor.

# Manganese

Highest value production of electrolytic manganese dioxide (EMD) for use in dry cell batteries.

Revenue generated from a single 50 MWe Salton Sea geothermal plant could equal $48 million per year at 95% capacity factor.

Production from the Salton Sea field could exceed world-wide consumption.

The 2006 value of Manganese is $1,380 per metric ton.

# Zinc

In late 1990's Cal Energy entered into a contract to construct a $177 million-facility to produce 30,000 metric tons of 99.9% pure zinc worth over $40 million per year.

By 2002 the plant was experiencing serious difficulties and was unfortunately closed in 2004. Despite this setback, the economic potential for zinc remains significantly important.

Zinc's current 2006 melt price is $2,416 per metric ton.

## Cesium

Cesium has a number of important applications. The most current application is as a high-density competent in drilling mud used in petroleum exploration.

Other applications include:

- television and night vision equipment
- solar photovotative cells
- removal of sulfur from crude oil
- medical applications
- specialty glass and fiber optics

The market equals 25,000+ kilograms per year. The current 2006 price for 99.98% Cesium is $52 per metric ton.

## Rubidium

Rubidum has a number of important applications. The principal application is in specialty glasses used in fiber optic telecommunication systems.

Other applications include:

- night vision devices
- photoelectric cells
- ultra centrifugal separation of nuclear acids and viruses

The market equals 1 to 2 metric tons per year. The current 2006 price for 99.98% Rubidium is as high as $79.90 per gram when purchased in small lots.

# Other Economic Benefits

Mammoth Pacific – Air Cooled 40 MWe

Serious loss of power during hot summer months exceeds 20% of net output.

Enhanced evaporative cooling using fiber glass fill could result in a recovery of up to 40% of the lost power and average 20%.

Based on a 10 MWe plant, this would amount to 400 kWe and $480 dollars per day if valued at 10¢ per kWh.

In order for enhance evaporative cooling to be employed a clean source of water is required.

Mammoth Pacific operators are testing reverse osmosis as a way to remove silica so that the geothermal brine can be used for this cooling system.

The recovered silica has proved to be of very high quality and could be worth up to several tens of dollars per ton.

# Dry cooling tower

# Enhanced evaporative cooling

## Conclusion

Mineral extraction can provide a number of economic benefits including:

- Extra energy/heat extraction
- Reduced operation and maintenance costs
- Recovery of marketable minerals and metals
- Recovery of lost electrical energy production through the use of evaporative cooling.

# The End