APPROACHES TO CONTROLLING SILICA DEPOSITION IN GEOTHERMAL PRODUCTION OPERATIONS

P.R. BARNETT[1] AND S.E. GARCIA[2]

[1]Kingston Morrison Limited, Auckland
[2]Philippine National Oil Company - Energy Development Corporation, Metro Manila, Philippines

SUMMARY - Concern with silica deposition is a significant constraint in the design and operation of geothermal steam fields. The usual design practice is to establish production plant flash pressure from brine silica concentrations which are in turn dictated by reservoir temperature. For a typical liquid dominated geothermal field this results in a production flash pressure of from 6 to 10 bara with waste brine temperatures from 160 to 180C. Under these conditions 40 to 45% of the produced energy is reinjected. Clearly, the efficiency of utilization of geothermal fluids can be improved considerably if problems with silica supersaturation can be controlled or avoided. This paper reviews means for controlling silica deposition based on a number of approaches - recovery of silica downstream of production plant; pH modification; chemical inhibition; dilution. Results of field trials at PNOC-EDC projects and elsewhere using some of these methods are discussed.

INTRODUCTION

Aqueous silica is a significant constraint in the design and operation of geothermal fields developed in high temperature hot water volcanic systems. This is due to the considerable potential which silica supersaturated brines have for depositing solid scales throughout fluid collection and disposal systems (FCDS), in locations such as:

- within two phase supply pipe lines and separator vessels;
- waste water disposal piping, particularly where long pipe runs are involved;
- within reinjection well bores (as well blockages) and in the reservoir volume around injection wellbores (as formation damage);

The most significant impact of silica deposition is in reinjection systems and there is a significant economic cost associated with such with respect to:

- reduced injection capacity which may require reduced steam field production and thus loss of revenue from steam sales and/or power generation ;
- well workovers to clear well bore blockages, generally in conjunction with acidizing to remove silica damage within the formation;
- the need to drill replacement injection wells if workovers do not result in recovery of lost injection well capacity.

This paper examines general considerations with respect to silica in establishing separator pressure during the design of steam field fluid collection and disposal systems (FCDS) and a number of other potentially useful techniques for controlling deposition in silica saturated brines are discussed, with particular reference to work presently being carried out by PNOC-EDC.

STEAM FIELD DESIGN CONSIDERATIONS

The concentration of aqueous silica in reservoir brine is controlled by the solubility of quartz which is directly related to reservoir temperature. In surface plant and injection wells, aqueous silica levels are controlled by equilibrium with amorphous silica, not quartz. A convenient means for expressing the equilibrium potential for the brine to deposit amorphous silica at any temperature T is the silica saturation index (SI):

$$SI\ (T) = \frac{[\text{Total } SiO_2 \text{ aq}]}{[\text{Solubility Amorphous Silica}] \text{ at } T}$$

Where SI is <=1.0 the brine is undersaturated with respect to amorphous silica and deposition will not occur. Conversely, where SI > 1.00 the brine is supersaturated and, from an equilibrium view point, must eventually deposit amorphous silica.

In steam field design, the usual practice for controlling silica deposition within surface facilities is to set flashplant separator pressure (SP) sufficiently high such that the temperature of the separated brine is greater than the saturation temperature of amorphous silica, i.e. where SI is <=1.00. In spite of recent research evidence (Flemming, 1986) which suggests that brines with SI's of up to 1.10 may lie within the limits of tolerable silica deposition, we believe that it is still desirable for steam field designers to adopt a separator pressure which results in an SI of <= 1.00 at field startup which allows some latitude for the effect of silica concentrations increasing with production time caused by pressure drawdown and reservoir boiling, and in some cases to severe reinjection returns.

As well as minimizing silica problems, the setting of higher separator pressure is also desirable for obtaining thermodynamic efficiencies which result in reduced turbine steam consumption rates at higher pressures. Against this, however, there is a competing interest in reducing separator pressure in order to:

- increase steam flows from production wells;
- maximize steam flash and thus decrease brine flows in order to minimize reinjection flow/capacity requirements;
- minimize thermal inefficiencies associated with rejection of brine at high temperatures, e.g. for a typical liquid dominated geothennal development with a single production flash pressure of 6 to 10 bara and waste brine temperatures ranging from 160 to 180C., approximately 45% of the produced energy is reinjected back into the reservoir with the brine.

These competing requirements must be resolved through a thermodynamic optimization of geothermal field output, constrained by silica saturation considerations. Frequently this does provide a clear answer, with either SI's of <= 1.00 being achieved at high separator pressure but with field output much reduced, or with optimal field output being achieved at lower pressure but with SI's being significantly greater than 1.00. Adjustment of separator pressure alone is thus not always sufficient to control silica problems in exploitation of high temperature volcanic geothermal systems.

MEANS FOR CONTROLLING SILICA DEPOSITION

There are a number of potentially useful techniques for controlling silica deposition in FCDS systems other than by separator pressure control alone. With a very large forward geothermal development program (see for example Javellana, this conference) PNOC has been recently examining these in detail in order to improve the efficiency of utilization of geothermal fluids and to minimize the potential for silica scaling in surface injection pipework systems which will contain pumps and will extend over long distances. The most useful of these techniques are now discussed in more detail:

pH Modification

Control of silica deposition through pH modification has been long recognized as a practical though relatively expensive technique (see for example Brown, 1983). There are two approaches depending on whether pH is raised or lowered :

- increasing the pH of a silica saturated brine to > 8.5 through the addition of alkali increases the solubility of amorphous silica quite dramatically thus rendering the brine silica-undersaturated;
- decreasing the pH through the addition of acid delays the rate at which polymerization of silica occurs in the saturated brine and thus also the rate of deposition of silica from the brine.

Of these two approaches, increasing the pH achieves complete control on deposition through changes in the solubility of amorphous silica, whereas, addition of acid simply increases the time before supersaturated silica eventually deposits. In spite of this, acid treatment - generally using mineral acids - is still preferred over alkali dosing because of some five fold cost advantage (Brown, 1983).

In the Philippines, Philippine Geothermal Inc., (PGI) has undertaken trials of acid dosing for control of silica deposition after extracting heat from waste brine from the 330 MWe Makiling-Banahaw geothermal power plants. These trials have proved successful and PGI have now committed to supply heat to a 16 MWe binary cycle power plant system using acid dosing to control silica deposition in the waste brine (J.M.Bodell, PGI, pers. comm).

PNOC is soon to commission at the Palinpinon geothennal field an agricultural drying plant heated by a flow of waste brine prior to deep injection. The silica saturation in the brine entering the plant's heat exchanger will be 1.2 and brine temperature will be dropped by 20C. The brine at the outlet of the heat exchanger will thus have an SI of 1.45. At this SI silica deposition is expected to be a problem within the heat exchanger and acid dosing or some other form of chemical control on scaling will have to be adopted to control it.

For the 650 MWe Leyte project which PNOC is now developing (Javellana, this conference) we recognize the potential benefits that acidification offers for decreasing deposition of silica in FCDS systems and reinjection wells.

In addition, we are keen to minimize atmospheric emissions of geothermal C02 in the interests of a Philippines contribution to international efforts in reducing global levels of greenhouse gases and global warming, and in support of applications for environmental and funding approvals. We are programming to inject at least some of the NCG off-gases from the Leyte 650 MWe power plants, directly into waste brine systems to reduce the pH of the brine to typically pH 5.5 to 6.0 (Barnett et. al., 1992). At these pH levels there is a significant reduction in both silica polymerization rate and deposition of silica scale (see for example, Hiriwatari and Yamauchi, 1990).

Chemical Inhibition

PNOC-EDC has an ongoing research association with a large, international company specializing in water treatment chemicals. Under this program a number of potential chemical inhibitors have been trialled at a test injection facility at Tongonan and results are encouraging far assuming that chemical inhibition of silica deposition in waste brines may be achievable at low chemical dose rates, and at acceptable cost.

Brine Dilution

One of the most obvious solutions to reducing silica saturations in geothermal brine is to simply dilute the brine with a secondary fluid which is low in silica. Readily available dilutants around geothermal fields include surface waters, steam condensate and lower silica brines. The temperature of the dilutant is important and should be maintained as high as possible. This is because as the concentration of aqueous silica in the brine decreases upon mixing with the dilutant, the effect of the temperature drop accompanying mixing can result in the saturation solubility of amorphous silica declining more quickly than is achievable from the effect of the dilution itself. A second important consideration is that dissolved oxygen in the dilutant is undesirable because of potential for corrosion of FCDS internals and the possible role of oxidation reactions in the brine chemistry leading to deposition of solid scales.

Cold surface water, such as river water, is thus a relatively poor dilutant having both low temperature and being saturated in oxygen. Cooling tower blowdown is more acceptable, being hotter, but is still less than ideal as it is also saturated with oxygen (with typically 6 to 7 mg/kg).

At the Palinpinon project we have generated a low silica dilutant by injecting steam into river water to both raise the temperature of the water to 100 C. and to strip out oxygen as the heated water boils. This technique is effective, reducing dissolved oxygen to levels of better than 0.5 mg/kg, however, it is an expensive option when the value of steam that is lost to power generation is considered.

We view the best source of dilutant for reducing silica saturation in brine is steam condensate from the discharge side of power plant hot well pumps. This has low levels of dissolved oxygen due to the degassing which occurs within the condenser. PNOC-EDC intends that all future steam field developments will use this condensate for brine dilution. In addition to reducing the potential for silica deposition in the brine system, this approach also usefully disposes of condensate in an environmentally aceptable manner. At this time it is not necessary in the Philippines to reinject cooling tower blowdown but this is likely to change in the future as environmental waste regulations become progressively more stringent.

Precipitation of Silica Prior to Reinjection

There are a number of process options for precipitating silica fiom waste brines prior to reinjection and these clearly provide a high level of protection from problems with silica deposition in downstream piping and reinjection facilities. Although these options tend to be capital intensive, plant and operating costs may be offset by the potential commercial value of silica and other chemical products that can be recovered.

Flash Crystallizer Clarifier

Flash crystallization is a kinetic method for controlling deposition of solids which was developed by UNOCAL and Bechtel in the early eighties for handling highly saline (20 to 30% TDS) geothermal brines at the Salton Sea. The method is based on the premise that if solids deposition can not be prevented then deposition should be allowed to occur on solid particles which are carried with the brine rather than allowed to settle out on plant surfaces.

The process offers a number of positive features, the most significant being that brine can be flashed down to atmospheric pressure thus resulting in a high utilization efficiency for geothermal fluids. Whether this is technology is appropriate for Philippine hot water volcanic geothemal systems is, for the following reasons, debatable;

brine salinities in Philippine geothermal systems are typically less than 10%of the Salton Sea brines. There is not then the very high supersaturation of mineral salts which provides the spontaneous nucleation and crystallization in the Salton Sea brines;

almost all solids are removed from the brine. This may be appropriate for the Salton Sea fluids which have a complex mix of metal sulfides, carbonates and

- silica which precipitate out, but this seems inappropriate for Philippine geothermal fields where the major concern is with deposition of silica only;
- a Substantial amount of waste mineral product is produced from flash crystallizer clarifiers for which little progress has made with commercial utilization other than "geocrete" as a roading material;
- capital and operating costs are high.

Precipitation of Silica *With/ Without* Recovery

As reviewed by Harper and Thain (1992), there has been considerable interest over the past twenty years in extraction of silica from geothermal waters as a means for conditioning waste brine prior to reinjection or discharge to the environment. Harper and Thain emphasize the commercial value of silica which *can* be specifically tailored to market requirements and they report on an operating plant at Kawerau which is producing 500 kg/day of high quality precipitated silica. It is apparent in these figures that most of the silica in the brine at the Kawerau plant is precipitated in the process and thus the residual waste brine after the precipitation process is well suited for problem-free injection at a low (<100C) temperature.

In contrast, PNOC have committed several geothemal development sectors to operate with "cold" injection systems in which waste brine is flashed to atmospheric pressure from primary or secondary flash/separator vessels. The brine is then held up for several hours in ageing ponds and injected after steam purging to strip out dissolved oxygen (Solis and Ruaya, 1992). With this process, approximately 70% of the total monomeric silica in the brine that is flashed to atmosphere polymerizes and approximately 30% of this latter component forms colloidal silica species which aggregate and precipitate. The remainder is injected.

"Cold" injection is a low cost process producing a low value silica product. PNOC-EDC intends to dispose of the precipitated silica, at least initially, in a land fill. There are, nonetheless, encouraging indications for a local market in the ceramics, glass and drilling industries. PNOC-EDC intends to further examine the potential for higher value, market specific processing of precipitated silica, along the lines of that reported by Harper and Thain, after the steam field is commissioned and the initial response of the reservoir to the production known.

The major reasons for PNOC selectively adopting "cold" injection is to enable injection of silica rich brines resulting from the following:

- a production sector at the Bacon Manito II development where reservoir temperatures are very higher, up to 330C., and concentrations of aqueous silica in brine at atmospheric pressure reach 1400 mg/kg. It is not possible to control silica saturation to manageable levels in these brines by simply raising separator pressure (SI would equal 1.50 at a separator pressure of 10 bara.) Furthermore, it is expected that in this particular sector, pressure drawdown over the first few years of production will lead to extensive evaporative boiling and eventually to localized block "dryout". Silica concentrations at atmospheric pressure are thus expected to increase to 2000-3000 mg/kg at which level silica scaling problems in surface pipework and injection wells would be unmanageable if a conventional "hot" reinjection system were to be adopted;

- a 16 MWe binary power plant which is to utilize waste heat from the reinjection brine flow from the 110 MWe Bacon-Manit0 I power plant, similar to the Makiling-Banahaw binary plant mentioned above. This same approach is also under consideration for use in the Leyte 650 MWe development where waste heat will also be extracted from waste brine lines to maximize thermodynamic efficiencies;

- well testing activities at exploration and development prospects where zero discharge restrictions have been imposed for environmental reasons. Cold injection in these situations allows for well testing to be carried out with all liquid wastes being transferred between wells, and ultimately reinjected, by gravity and/or pumped, low pressure piping systems.

SUMMARY AND CONCLUSIONS

There are substantial potential benefits to geothermal operators if silica deposition can be controlled during utilization of geothennal fluids;

- brine line cleaning and maintenance can be eliminated
- building of redundant, back-up reinjection systems can be eliminated
- the need to mechanically drill out well bore scale in injection wells, and to acidize to recover formation damage in the reservoir around the injection wellbore, can be reduced, if not eliminated
- the utilization efficiency of geothermal fluids can be increased significantly by cascading secondary heat recovery units downstream of primary flash/separator vessels which are conventionally constrained by silica saturation concerns.

- commercial value of recoverable minerals if precipitated silica is extracted

In PNOC-EDC's large forward development program these .benefits are being recognized and we are actively pursuing the following methods for control of silica scaling problems;

- optimization of separator pressure with respect to silica saturation
- brine dilution with deoxygenated steam condensate
- injection of CO_2 and chemical inhibitors
- "cold" injection with increasing future interest in the commercial potential and value of silica precipitates

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