SILICA SCALING TRIAL AND INJECTION OF COLD SEPARATED GEOTHERMAL WATER AT WAIRAKEI, NEW ZEALAND

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ABSTRACT

The depositional characteristics that might be associated with the injection of cold separated geothermal water (SGW) were investigated in a month long trial at the Wairakei geothermal field. This was achieved by passing 2000 m^3 of aged and cooled SGW through a bed (250 mm diameter 4.2 m long pipe) packed with dacite chips 5-8 mm. No silica was deposited in the packed bed but <50 g of an iron and silica rich (32wt% and 33wt% respectively) scale deposited at the inlet screen. It is likely that the colloidal silica was flocculated by the iron corrosion product.

Based on these positive results Contact Energy implemented an injection trial, with 200 t/hr of cold SGW injected into a cooler outfield sector west of the field, which successfully ran for 10 months.

1. INTRODUCTION

The reinjection scheme for the Te Mihi Power Station, presently under construction for Contact Energy Ltd at Wairakei, is designed for injection of SGW and condensate. SGW is diverted directly to reinjection while condensate is first diverted to a large holding pond and from there subsequently pumped to the reinjection wells.

However the intention is that during power station or steamfield outages SGW will also be discharged to the holding pond. The silica scaling potential of this fluid will be highest due to maximum steam loss and adiabatic cooling. On aging and subsequent conductive cooling the driving force for the direct deposition of the dissolved silica decreases while the potential for colloidal deposition and well plugging increases.

Although silica scaling is qualitatively well understood reliable predictions of scaling under these conditions is not possible (Mroczek et al., 2000; Mroczek et al, 2011). A comprehensive site specific trial was undertaken to evaluate the scaling and depositional characteristics of the cold SGW.

2. EXPERIMENT

2.1 Te Mihi Holding Pond

The total holding pond capacity is about 77,000m^3 and the pond inlet and outlet are on the same side, separated by a ~50m long concrete wall. The outlet sump receives fluid from the pond forebay which has a 4000m^3 capacity and an operating level of 1.6m. The large body of cold water in the forebay is intended to mix and cool the SGW in the event of a dump. Two designs are being considered for the condensate flows. In the first design the condensate is pumped directly into the outlet sump. This would further cool (if required) the SGW mixture to below the maximum allowable 45^{o}C and dilutes the brine. In contrast in the second alternative design, the cold condensate is mixed with the hot (>80^{o}C) SGW as it flows to the pond in an open channel. In the latter case the SGW is both diluted and cooled prior to start of silica polymerization which will reduce the colloid number and size. Intuitively to minimize well bore and formation scaling, the second design is preferred. However during the actual scaling trial, only SGW was discharged to the pond at a rate of 250t/hr. With this, no experiments could be undertaken to differentiate between the two earlier dilution design options. The trial with undiluted SGW is however worst case with respect to scaling in the packed bed, pipes and also in the formation.

2.2 Equipment

A simplified schematic of the experimental test rig is shown in Figure 1. A 200 mm diameter sch. 40 mild steel pipe was filled with ¼" dacite gravel (pea size), with bigger gravel size at the mouth of each opening. This prevented the ¼" chip from blocking the 1/8" mesh which held the gravel in place. Mild steel 1 m length pipe sections (25 mm diameter) were placed in line before and after the bed. The rig was inclined to avoid airlocks and to keep the bed full of liquid.

The pump flow from the forebay was 55 m^3/hr of which only ~2 m3/hr was diverted through the packed bed and the rest was dumped back into the pond via a nearby drain. The waste from the packed bed was piped back into the pond about 200 m from the forebay. Pressures and flows were continuously logged and initially the experiment was monitored daily. Inlet samples were collected for pH, total and dissolved (molybdate active) silica, chloride and colloid particle size analysis. After a few days of stable operation, the monitoring was reduced to twice a week with samples only being collected once a week. The experiment ran successfully for 43 days with over 2000 m^3 of cold SGW having been passed through the bed

2.3 Scaling Results

No silica visibly deposited on the gravel packing, plastic waste pipes or on the concrete bypass splash zone of the drain.

However over the course of the experiment the pressure differential between the inlet and outlet of the packed bed slowly increased. This was caused by the accumulation of soft red scale on the downstream side of the inlet mesh holding the gravel in. There was also a thin layer of a soft mushy deposit on the cone before the inlet mesh which was removed and weighted. Scale was also removed from the weighed 1m inlet and outlet test pipe pieces located upstream and downstream of the packed bed.

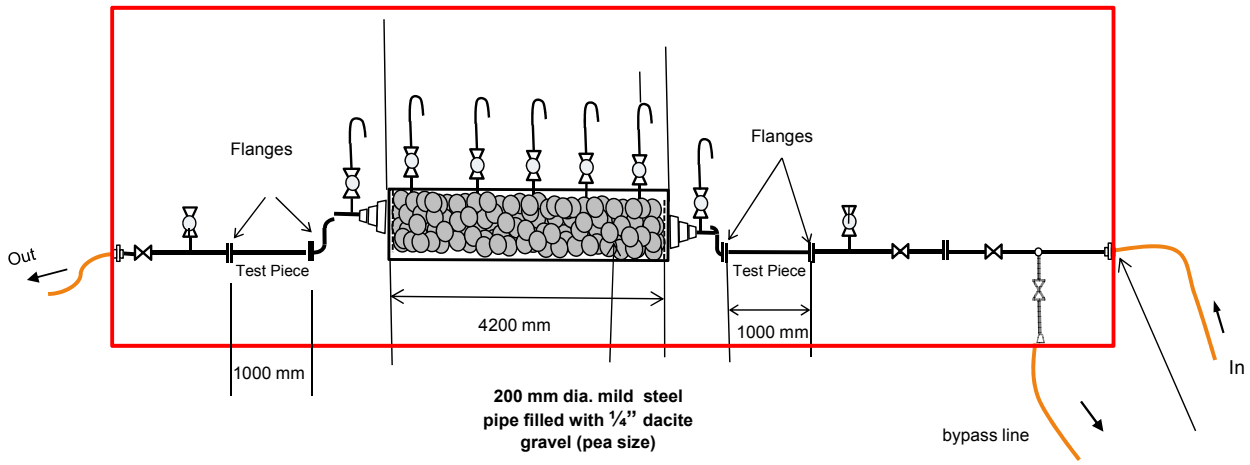

Figure 1: Simplified Test Rig Schematic.

Table 1: Scale Analysis

Test Piece (pipes 1 m x 25 mm ID)	Weight Scale (g)	wt% Aluminum	wt% Arsenic	wt% Calcium	wt% Iron	wt% Silica as SiO_2	wt% Sodium	wt% Total S as SO_4
Inlet pipe	14	0.07	2	0.19	68.9	24.9	0.25	0.26
Outlet pipe	20	0.04	1.33	0.45	44.3	14.4	0.12	0.19
Inlet cone	3.4	0.06	2.5	0.16	29.6	33.1	0.15	0.01
Inlet screen downstream face	5.8	0.06	2.6	0.27	31.7	32.2	0.22	0.06

The scale visually appeared to consist primarily of corrosion product due to reaction of aerated high Cl water with low carbon steel pipe (steam pipe grade). The scale analyses are listed in Table 1.

The brine chemistry during the course of the experiment showed that the dissolved silica concentration (~ 167 mg/kg) to be up to 1.5 x the solubility of amorphous silica at the typical fluid temperature of 20 – 30 ^{o}C. The bulk of the total silica is already polymerized and at this temperature the silica saturation does not reflect a high rate of polymerization or deposition of dissolved silica.

The total silica concentration in the pond varied between 695 and 755 mg/L and the chloride between 2223 and 2374 mg/L, probably reflecting dilution by runoff. The colloidal silica concentration is the difference between the total molybdate active silica concentration which varied between 493 and 596 mg/L. This indicates a high sediment load of colloidal silica particles in the fluid.

The mean average size of the colloidal particles (Nanotrac 150) was 32 nm and this did not vary significantly throughout the experiment (range 27 – 37 nm). The particle size was uniformly distributed around the mean (10th decile 22 nm and 90th decile 43 nm) with no discrete populations of smaller or larger particle distributions which could indicate agglomeration.

3. DISCUSSION

3.1 Scaling Trial

The direct deposition of dissolved silica results in a hard dense scale. Scaling can be particularly severe during silica polymerization where there are high concentrations of both dissolved and colloidal silica (Weres and App, 1982; Brown, 2011). The latter results in a hard but porous scale due to the cementation of colloidal silica particles by dissolved silica. However in this experiment the low temperatures and dissolved silica concentration close to amorphous silica saturation meant that the driving force of deposition of dissolved silica was very low and consequently no scaling of this type was observed.

However colloidal silica on its own can deposit as a soft scale but the extent to which this occurs depends on hydrodynamics and other factors such as particle size and fluid chemistry particularly pH, salinity and trace metals (Brown, 2011). This type of deposition did not occur on the gravel in the packed bed. However the concentration of silica in scale removed from the screen, inlet cone and inlet test pieces were high, varying between 25 – 33 wt % (Table 1). It is highly likely that the colloidal silica was flocculated by the iron corrosion product, especially Fe^{3+}. Only a fraction of the total silica (<0.01%) deposited but together with the corrosion products, this effectively started blocking the inlet screen.

Recent utilization of Wairakei reinjection brine (Mroczek et al., 2011) showed that in the absence of excess dissolved silica the particles in the size range observed in the present experiments did not deposit. In the experiments of Mroczek et al. (2011), the SGW was rapidly cooled which limited the colloid size and subsequently reduced aggregation. Similar mechanisms may also have been operating at the Te Mihi pond where a relatively small SGW flow mixes with the much larger body of cold pond SGW. These results are also consistent with earlier experiments in pipes and packed beds at Rotokawa (Mroczek and McDowell, 1990) were the silica deposition rate decreased with increasing colloidal silica fraction.

Even though negligible scaling occurred in the pipes and packed bed there is still a risk associated in injecting this fluid. This is because the fracture permeability of the accepting formation may be too low to accept colloidal silica particles of mean 30 nm but ranging up to 43 nm. This could only be ascertained by an actual injection test.

3.2 SGW Injection Trial

As the scaling potential of the cold SGW was shown to be low, Contact Energy Ltd commenced injecting mostly into outfield wells WK681 and WK682 at separate periods and at a rate of not more than 270t/h. The injection rate was the maximum allowed under the regulatory consents. These outfield wells are located west of the Wairakei geothermal field with deep maximum temperature of about 70°C. The wells are cased to depths of 550m to 650m with total depth of 900m to 1250m. Main permeable zones are located at 500m to 800m level with injectivity of 7t/h/b to 9t/h/b. An injection monitoring programme was set up to assess the pressure, temperature, and fluid chemistry response of nearby monitoring wells in order to evaluate the viability of the outfield injection and effect on the reservoir. The trial has been running for 10 months now and is still ongoing. The injectivity of the wells so far have not shown any indications of deposition of silica either as a filter cake on the well bore or in the formation.

In recent time, SGW injection has also commenced to an infield well at Karapiti.

4. CONCLUSION

The month long scaling experiment in a test rig and characterization of the SGW silica chemistry showed that the silica scaling potential of the cold SGW was low. The experiment ran successfully for 43 days with over 2000 m3 of cold SGW having been passed through the bed without any significant deposition of silica.

However, the viability of injecting cold brine was ultimately proven by an actual injection trial which showed that the fracture permeability of the accepting formation was sufficiently high to accept colloidal silica particles of mean 30 nm.

These results are important as it means that Contact Energy have the considerable added flexibility of safe disposal of cold SGW resulting from plant outages and tests without endangering their injection capacity with silica deposition.

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