Pressure Drops due to Silica Scaling

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Abstract

Experience with reinjection returns in many geothermal fields has prompted a move towards injecting waste fluids at some distance from the production field. This means that often, reinjection pipelines cover very long distances. If the waste water in the pipelines is supersaturated with respect to amorphous silica, then the deposition of silica in these pipelines is almost certain. Although the deposit may be of negligble thickness, the inner surface characteristics of the pipe will be different to those of clean mild steel.

During a silica scaling experiment, geothermal brine was passed through a series of pipes of different sizes and over a period of three weeks, silica scale formed on the inner sutface. The pressure drop along a distance of approximately 5m was measured by a water manometer in all test pipe sections. Significant pressure drop was observed during this time and can be correlated with the increase in the friction factor of the pipe walls due to silica scaling.

1.0 INTRODUCTION

As more experience is gained with disposal of separated water in geothermal systems, the problem of reinjection returns has meant that reinjection sectors are moving further from production areas. This often results in long reinjection pipelines containing water which is supersaturated with respect to silica. The design of these pipelines must take into account the pressure drop along the pipeline, and a factor in this calculation is the roughness of the pipe. At present, the normal practise is to use a standard roughness (0.046mm) for a clean commercial steel pipe as given in the Moody (1944) diagram with allowance for some change with time due to silica scaling. Typical roughness values assigned for scaled pipes are in the range 0.1mm and 0.2mm, which is classed as between "light rust" and "heavily scaled" surfaces. Moody derived his diagram based on experiments with nominally spherical particles of sand and the roughness of various surfaces is compared with the equivalent sand grain sizes. Where the surface scale is not spherical, it is difficult to estimate an equivalent surface roughness. Thus, the roughness that should be allowed where silica has been deposited on to the pipe surface has been somewhat arbitrarily assigned in the past. A report (Stock, 1990) of the effect of silica deposition was published in 1990 for a reinjection line at the Dixie Valley geothermal development and some roughness heights were able to be calculated. It was found that the roughness was much greater than originally expected with a maximum value of 38mm in one case. These measurements were complicated by a number of factors. Amongst these were the uncertainty in correcting for pressure drops around bends and the somewhat low precision of the pressure measurements.

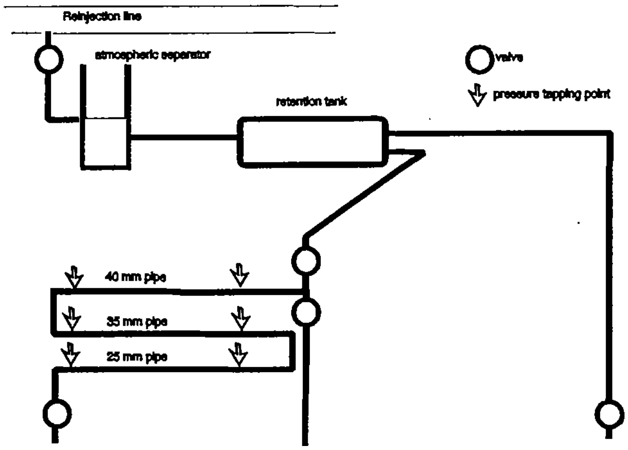
During an investigation into silica scaling at the Berlin Geothermal field in El Salvador, data on pressure drop due to silica scaling was required for the design of the reinjection system. Experiments on the rate of silica deposition were used to accurately define the change in roughness due to silica scaling.

2.0 EXPERIMENTAL

The experimental plant is shown diagrammatically in Figure 1.

Water from an atmospheric separator was piped to a retention tank to allow the silica to polymerise and then led through a series of three different sizes of pipe - 40, 35 and 25 mm in diameter. The flow was adjusted to 1 litre/second by adjustment of the exit valve. This corresponds to a design velocity of 0.78, 1.03 and 1.87 m/sec in the 40, 35 and 25 mm lines respectively. Unfortunately, silica deposition in the exit valve and in the line meant that continual adjustment was necessary.

Figure 1



Part way through the experiment, the pressure drop through the 25 mm line became so high that the flow rate of 1.0 Vsec could not be maintained. At this point, the 25mm pipeline was removed and the experiment continued with the 35mm and 40 mm lines only. The temperature of the water was 95 "C. The test ran for 17 days. Each pipe size was represented by a standard length of schedule 40 steel pipe. Pressure tappings were placed at either end of the pipe lengths with a suitable allowance to avoid the turbulence of the bends. This gave about 5m distance between pressure tappings. The presure was measured using a water manometer. At each pressure reading, the flow was monitored. On the 15th day after the silica scale was well developed, a series of pressures was measured at different flow rates from 1.0 Vsec to 0.6 *Vs.* At the end of the experiment, three 20 cm sections were removed from each pipe for analysis.

3.0 RESULTS

At the end of the experiment, pipe sections were cut and the scale characterised. The silica that was deposited was identical in all of the three different pipe sizes and consisted of a series of ridges of silica scale inclined at an angle of around 50" - 60" into the direction of the flow fom the long dimension of the pipe surface. The ridges run at right angles to the pipe length and are not continuous around a cricumference. These ridges were about 0.8 to 1.0 mm in height and the average spacing was 1-1.5mm in the 40mm pipe, 2-3mm in the 35mm pipe and 1-3mm in the 25mm pipe. In between the ridges, there was a very porous deposit *of* silica which was about 0.3 - 0.5 mm thick. The deposit was very adherent to the pipe surface. Such silica scale morphology is very common. Scanning electron micrographs at low magnification of the scale on the first sample from the 35mm pipe is shown in Figure 2. The ridges can be clearly seen in this low magnification photomicrograph. At higher magnification in Figure 3, the colloidal nature of the silica is evident. The smallest particles discernible have aggregated to form larger coherent particles around 20 µm in diameter. The original particles seem to have been in the range of 0.1-1.0 pm. The high porosity of the scale is very evident from these high magnification SEM micrographs, where crevices can be seen between the large aggregates.

The pressure differentials recorded using the water manometer depend on the mass flow, but since the flow was measured concurrently with the pressure drop measurements, a correction can be made. The pressure drop *(AP)* is given by:

$$AP = \lambda.L.\rho.v^2 / (2.D)$$

where λ is the friction factor, L is the length between pressure tappings, ρ is the density of the fluid, v is the velocity, and D is the diameter of the pipe. By substituting $4m/\rho\pi D^2$ for the velocity, where m is the mass flow, it can be shown that the *AP* is proportional to the mass flow squared and inversely proportional to the diameter to the 5th power. ie $AP \propto m^2/D^5$. Since at any temperature, the density is constant, the mass flow is proportional to the volume flow. The function $\Delta P*D^5/(\text{volume flow})^2$ has been plotted against time for the three different pipe sections. These plots are shown in Figure 4.

Figure 2

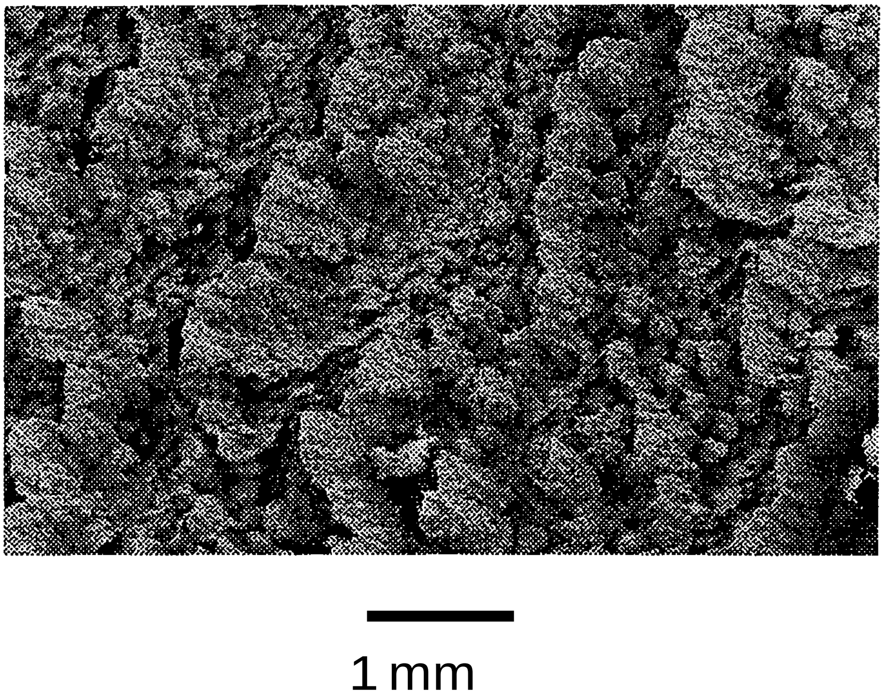
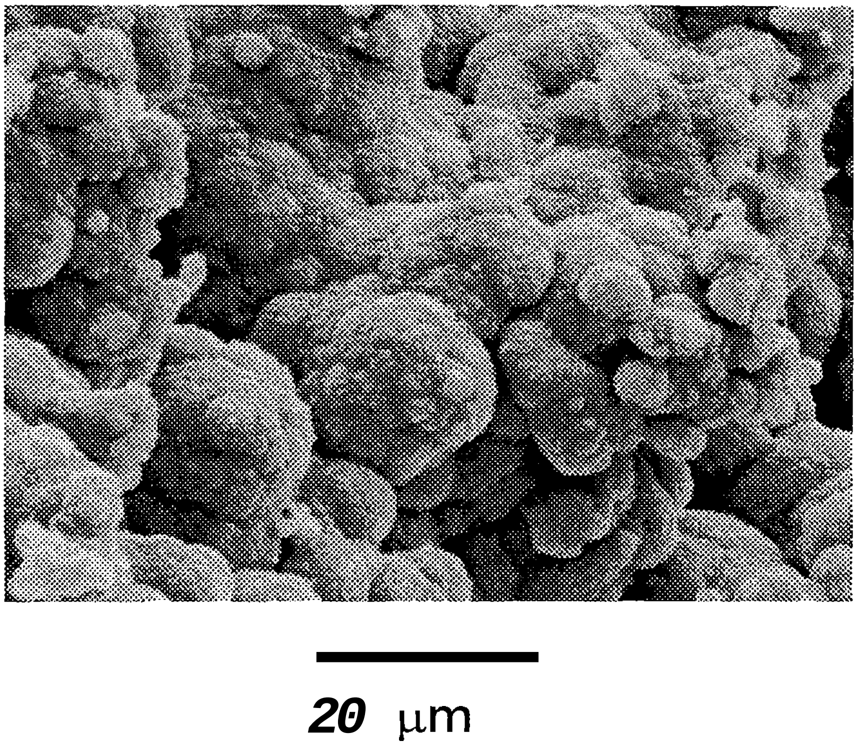


Figure 3



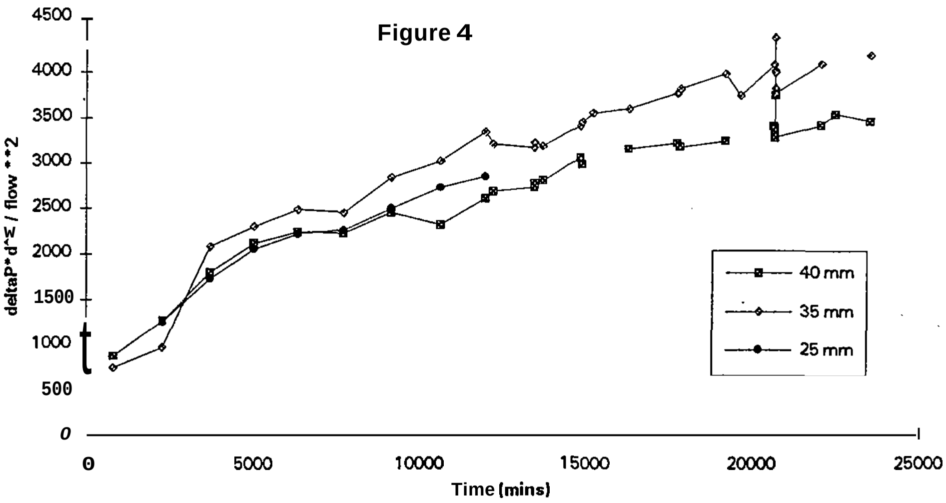


Figure 4

There is remarkable agreement between the three sets of results and they show a trend of $\Delta P*D^5/m^2$ upwards with time indicating that either the friction factor is increasing with time or the real diameter is decreasing. Of course, both of these are happening simultaneously. The friction factor is a function of the roughness of the pipe and with the increase in the silica scaling - particularly in this type of scaling with protruding ridges - the roughness of the pipe surface increases. The relationship between the roughness factor and the friction factor has been reviewed by Chen (1984). In order to calculate roughness, we have used the modified Blasius equation which is:

$$\lambda = 0.3164 \left[\frac{1}{Re^{0.83}} + 0.11\left(\frac{\varepsilon}{D}\right) \right]^{0.3}$$

where Re is the Reynold's number and ε is the effective roughness height. Using this expression, we have calculated the effective roughness for each of the data points in Figure 4 and the calculated roughness heights are given in Figures 5,6 and7. The calculation of the roughness is very sensitive to the diameter of the pipe and this of course decreased slightly during the experiment due to the build up of silica scale. The reduced diameter of the pipes was measured at the end of the experiment and a linear decrease in diameter with time to this value was assumed. Therefore two'plots are shown on each graph - one assuming constant diameter and the other assuming the linear decrease in diameter.

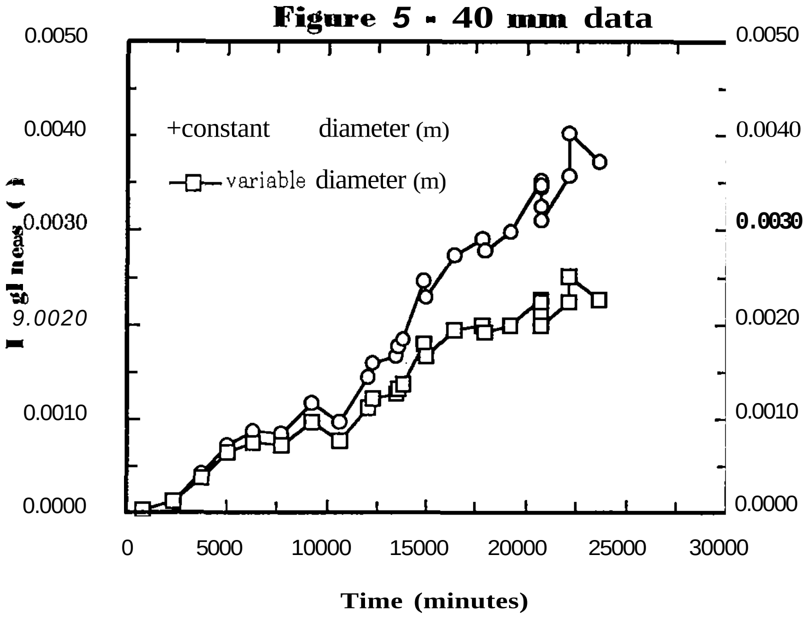


Figure 5 - 40 mm data

Figure 6 • 35 mm data

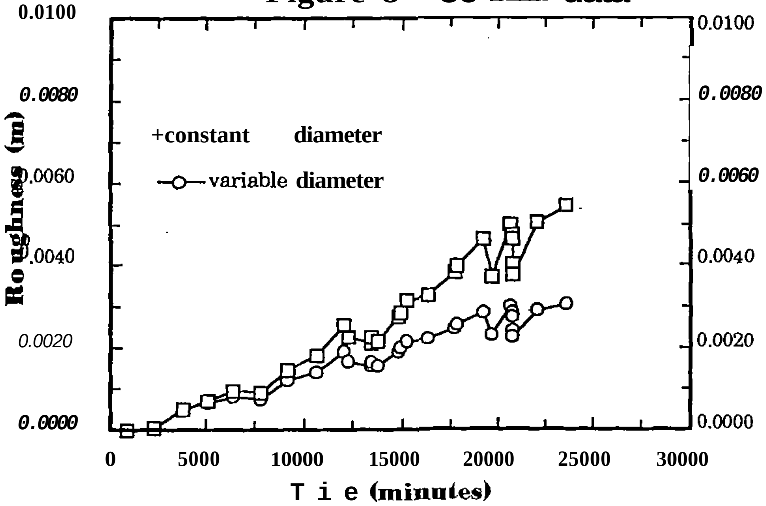
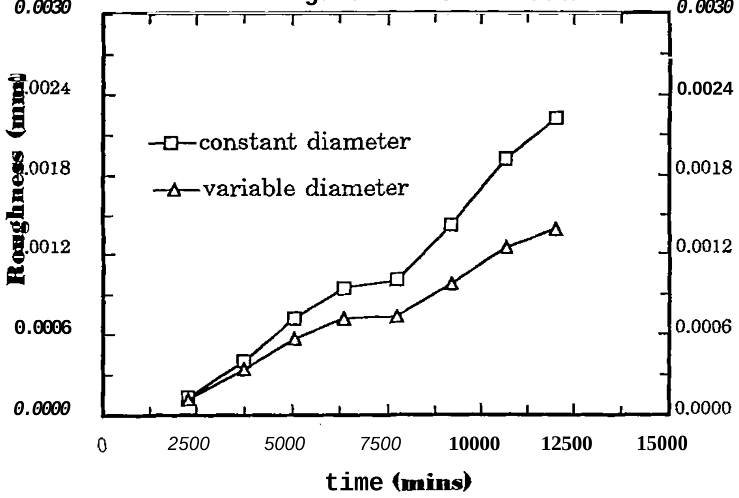


Figure 7 - 25 mm data



After correcting for the diameter changes, it can be seen that the roughness is approaching an equivalent height of around 2.5mm for the 40 mm pipe, 3.0 mm for the 35 mm pipe and 1.5mm for the 25mm pipe. This is almost two orders of magnitude greater than that expected for clean steel pipe (0.046mm), and places the fluid in these conditions in the "complete turbulence, rough pipes" area of the Moody diagram. In this case, reduction of the velocity to quite low Reynold's numbers (—10,000) has no effect on the friction factor for pressure drop calculations.

This means that silica scaling definitely needs to be taken into account when designing reinjection lines and appropriate friction factors assigned to the pipe surface. For instance, consider the case of a 1.5 km, 6" (150mm) reinjection pipe on a level surface. Using design conditions of a clean steel surface, the pressure drop along this pipeline would be 1.7 Bar. However, if the pipe has a lining of silica scale similar to that found above, then the pressure drop will be 5.5 Bar. This is a very significant difference and could have quite severe consequences. For instance, the reduced pressure at the injection wellhead, could in fact allow it to discharge with quite disturbing consequences. Similarly, in a network of reinjection pipework, the balance between flow paths could be radically altered by the changes induced by silica scaling.

4.0 ACKNOWLEDGEMENTS

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