

Heat Exchanger Research

Heat exchanger fouling due to scale formation is a common problem. A particularly severe application is heat transfer for the heat exchanger of the 1 megawatt VPC system at Coso geothermal resource. Generation of power from low temperature geothermal resources requires the transfer of heat from the brine to a binary power system. Conventional binary power systems are limited by the amount of heat that can be transferred for conversion by the boiling process. Advanced power cycles such as Energent's Variable Phase Cycle or the Kalina cycle are able to capture more heat from the geothermal resource and produce more power. The only limitation to these advanced cycles is the extent to which the brine temperature can be lowered in the heat exchanger without producing scaling. These advanced cycles have the potential of producing 20 – 30% more power than a conventional binary power system.

To determine the best method of scale reduction, a research program was carried out at a geothermal resource having a high scaling potential. The primary source of scaling was silica which was found in the brine at a level of 528 ppm.

A scaling test system with several experiments was designed and operated at Coso geothermal resource with brine having a high scaling potential. Several methods were investigated at the brine temperature of 235°F. The experiments involved injection of four potential anti-scaling chemicals; operation of an electromagnetic device; and the circulation of abradable balls through the brine passages. The test apparatus is shown in Figure 1. Brine from a power plant separator flowed through tubes which had the scale reduction methods introduced. The tubes were immersed in a cooling water bath to reduce the temperature. The temperature of the brine was reduced to an average temperature of 125°F.

The most promising method was found to be circulation of the abradable balls through the brine passage. Abradable balls are routinely used for the scaling of condenser tubes. The balls used for the brine descaling had a special high temperature rubber formulation with hard particles inserted in a sponge matrix. Table 1 shows the results of operation for 30 days of flowing brine. As can be seen, the abradable balls resulted in the lowest scale buildup at the tube exit. Two of the chemicals had a low scale buildup at the inlet of the tube, but resulted in a buildup of more than three times that of the abradable balls at the exit. A probable reason is the recommended injection rate was too low. Future tests will be done increasing the vendor's recommendation for the injection rate. However, chemical injection is costly and has environmental consequences. Increasing the rate can substantially increase the operating cost.

The key result is the ability to operate at the low-temperature 125°F with only a moderate buildup of scale. For advanced low-temperature cycles, such as the Variable Phase Cycle or Kalina Cycle, the lower brine temperature will result in a 20-30% increase in power production from low temperature resources.

An preliminary design of an abradable ball system ("ABS") was developed for the heat exchanger of the 1 megawatt VPC system at Coso geothermal resource. The ABS will be installed and demonstrated in Phase 2 of this project, increasing the power production above that which is possible with conventional binary power systems.

Figure 1 shows the test apparatus used for the scaling experiments. The test apparatus consisted of a brine separator, a flow control valve, a test tube, and a cooling water bath. The test tube was immersed in the cooling water bath and the brine flowed through the test tube. The test tube was surrounded by a cooling water bath to reduce the temperature of the brine.

Table 1 shows the results of operation for 30 days of flowing brine. The table shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 2 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 3 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 4 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 5 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 6 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 7 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 8 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 9 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 10 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 11 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 12 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 13 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 14 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 15 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 16 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 17 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 18 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 19 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 20 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 21 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 22 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 23 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 24 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 25 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.

Figure 26 shows the results of operation for 30 days of flowing brine. The figure shows the scale buildup at the inlet and exit of the test tube for four different methods: abradable balls, chemical injection, electromagnetic device, and no treatment. The abradable balls resulted in the lowest scale buildup at the tube exit.