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Reykjanes Geothermal Field: Control of Silica Scaling in Separator by Flashing of Brine in Critical Nozzles.

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ABSTRACT

In the Reykjanes geothermal power plant, the steam is separated from brine at high pressure and the hot brine disposed off. Bottoming unit is now being developed in which the hot brine will be flashed in two stages and the medium- and low-pressure steam used in a dual stage turbine to generate 30 MW of electricity. Because of high silica concentration and high salinity severe scaling will occur when the brine is flashed to lower temperature in a separator. The use of acid for scale mitigation, although effective, is considered unattractive and therefore a new separator technology was developed to control the silica scaling without use of chemicals. Experience shows that silica scaling rate in two-phase steam and brine is considerably less than in single phase brine and the idea was that by operating the separator with minimum brine level the scaling problem would be minimized. Also, by controlling the flow with fixed diameter nozzles with critical flow, the separator would be valve-less and cleaning of the scale would be possible by reaming the nozzles without stopping the flow. A double flash experimental critical nozzle separator was designed for 25 kg/s of 207 °C brine, which was flashed in two stages at 155 °C and 108 °C. The pressure in the low-pressure separator was controlled by barometric pipe in an atmospheric flashing tank designed to allow easy access for cleaning. The tests were successful and showed that the separators could be operated with minimal maintenance. The design is now being scaled up for full size separation of 410 kg/s of brine.

1. INTRODUCTION

HS-orka operates a 100 MW power plant in the Reykjanes geothermal field in Iceland. The plant is fed with steam from 1030 to 2800 m deep wells which tap 250 to 320 °C hot brine of seawater salinity from the geothermal reservoir. In the power plant, 2 x 85 kg/s of steam is separated from the brine at 18 bar separator pressure. The steam is used for powering two 50 MW turbines and the exhaust steam is condensed at 40-45 °C in surface condensers. The non-condensable gas is extracted from the condenser and discharged through a chimney. The separated 207 °C hot brine is partly reinjected and partly disposed off into the ocean. The energy content of the disposed brine is considerable and can be used to generate at least 30 MW of electricity.

Because of high silica concentration and high salinity, the brine, if not treated in some way, will cause severe scaling when flashed or cooled down in heat extraction equipment. A decisive factor for selection of process scheme is the possibility of trouble-free operation in respect to scaling and corrosion.

The scaling potential of the Reykjanes brine has been extensively tested in order to control the scaling in a bottoming process. Experiments in a high-pressure reactor showed that the silica scaling rate could be affected by various means such a by diluting with condensate, pH modification or addition silica seeding particles, Hauksson and Þórhallsson (2003). Brine treatment for reducing silica scaling rate was then tested in an experimental heat exchanger. Acidification was successful but the pH had to be lowered below pH of 3.5 to be sufficiently effective calling for expensive material for heat exchanger surface, Hauksson et al. (2006). Other methods were not effective or entirely unsuccessful such as addition of silica seeds which accelerated the scaling instead of reducing it, Hauksson (2009). The use of heat exchanger was ruled out as technically viable method for the bottoming plant and further tests were conducted with a small experimental double flashing unit where the brine from the high-pressure separators was flashed in two stages at 150 °C and 100 °C. Experiments with acidification of the brine prior to flashing in separator was successful while tests with dispersing inhibitor had no measurable effect. pH modification to pH of 4.5 was sufficient to lower the scaling rate in the effluent brine to 2 mm/y which is sufficient for operation of the separator units. For reinjection the acidified brine effluent will need to be diluted 50% with condensate to stabilize the silica in the brine for reinjection, Hauksson (2011). Although the pH modification is a technical viable method the use of acid which has to be imported was not attractive and therefore it was decided to develop a separator process which could be operated without the use of acid. An experimental separator unit was designed for 25 kg/s of 207 °C brine, which was flashed in two stages at 155 °C and 108 °C and its testing and development is described in this paper.

2. SILICA SCALING CHEMISTRY

The brine in the Reykjanes reservoir is of seawater salinity. The chemical composition differs from that of seawater because of equilibrium with minerals in the rock at high temperature. The magnesium (Mg) and sulphate (SO_4) concentration is much lower while the calcium (Ca) and potassium (K) concentration is higher. Sodium (Na) and chloride (Cl) concentration of the brine in the reservoir is similar to seawater concentration. Because of the high chloride content and high temperature, the solubility of metals such as iron (Fe), manganese (Mn), zinc (Zn) and lead (Pb) is considerable in the reservoir brine. Concentration of silica (SiO_2) is controlled by equilibrium with quartz in the rock at reservoir temperature. The brine enters the wells in most cases in a liquid form and flashes when the pressure drops on its way up the well. When the brine flashes in the well, dissolved gases such as CO_2 and H_2S escape the brine and the pH increases. This causes in-equilibrium in the brine and supersaturation of various metal sulfides and silicates. The sulfides of zinc, lead etc. precipitate fast and form a scale inside the well and in the pipeline close to the well. The metal silicates precipitate more slowly and form scale in the brine transmission lines and separator plant. At the plant separation pressure of 18 bar the silica concentration is 750 mg/kg and below the amorphous silica solubility in the brine at 207 °C. Condensate is mixed with the high-pressure brine to avoid flashing in brine transfer pipes. This lowers the temperature to 207°C. When the brine is flashed from 207 °C to 155 °C the silica concentration increases to 840 mg/kg and the silica supersaturation ratio becomes 1.36. Silica starts to precipitate but at a slow rate forming amorphous silica scale. At this stage iron and manganese is coprecipitated with the silica which makes it hard. When the brine enters the next stage and is flashed to 108 °C the silica concentration increases to 932 mg/kg and the silica supersaturation ratio becomes 2.39. At the high supersaturation and high salinity, the silica precipitates rapidly and forms soft white amorphous silica scale. Further flashing to atmospheric pressure increases the silica concentration to 940 mg/kg and precipitation rate is escalated at the high silica saturation ratio of 2.65 and silica rapidly precipitates and forms silica scale on surface and silica particles in the brine.

One particulate feature of silica scaling has been noticed during operation of the processing equipment in Svartsengi and Reykjanes. This is the effect of two-phase flow on the scaling rate in pipes and equipment. The scaling rate is considerably lower in two phase brine and steam flow than when the brine is separated from the steam and flows as a single-phase brine. The reason for this is not known but it may be caused by adhesion of steam phase to the surface thus preventing brine contact with the surface and silica deposition. This was e.g. noticed during reinjection of silica supersaturated brine in Svartsengi. The brine flashed over an orifice and scaling on the upstream in single phase brine was 5 mm year while on the downside in two-phase flow it was negligible, Hauksson (1982). For heating the brine in the Blue Lagoon supersaturated brine was injected into the lagoon through nozzles. Scaling was minimal and the nozzles could be operated for long time without cleaning. This feature is also utilized in the silencers for the brine effluent in the Reykjanes plant. The brine at 207 °C is injected vertically through narrow nozzles into the effluent brine in the silencers basin which considerably reduces the formation of silica scale in the silencer.

3. EXPERIMENTAL SEPARATOR UNIT

An experimental two-stage separator unit was built close to the high-pressure (HP) separators of the power plant and connected to the discharge pipes from the HP separators. It was capable of separating 25 kg/s of 207 °C brine and produce 2.8 kg/s of MP-steam at 155 °C and 2.0 kg/s of LP-steam at 108 °C. Each separator was combined with horizontal droplet settler. The flow pattern inside the separators could be studied through sight glasses. The installed experimental separator is shown in Figure 1. The separator unit was constructed above an abandoned silencer basin. In the figure, one of two brine pipes with five injecting nozzles which was used in the silencer can still be seen in the basin.

Figure 1: Two stage experimental separator unit and effluent basin.

Each separator is a combination of a vertical section and a horizontal droplet settler. The inflow of 207 °C brine was controlled by a fixed diameter nozzle with critical flow. The steam outlet valve controlled the pressure in the MP-separator automatically. A fixed diameter nozzle with critical flow also controlled the flow of brine from MP-separator into the LP-separator. A guided radar level sensor in an external pipe monitored the level in the MP-separator. The pressure in LP-separator unit was manually adjusted so that the level of brine in the barometric pipe in the basin was at 4 meters depth in the basin and close to the bottom of the pipe. The horizontal section of the separators acted as droplet settler. It contained a vane mist eliminator to improve the separator efficiency. The design of the separator with respect of separator efficiency is described in a separate paper at this convention, Þórólfsson et al. (2020).

Full flow (25 kg/s) was achieved by inlet nozzle of 39 mm diameter in the LP separator and nozzle of 66 mm diameter was sufficient to control the level in the MP-separator. The flow characteristics in the separator could be studied through the sight glasses and the design was changed several times to optimize the operation. The initial and final nozzle configuration is shown in Figure 2. To begin with the nozzles were directed vertically into the vertical section of the separator with the idea that the brine would flow to the bottom and the steam would flow outward and up and be separated from the brine. By this configuration the scaling in the vertical section was minimized but the separating efficiency was very poor and brine flowed into the horizontal section with heavy scaling. Several different designs of splash shields were tested and the diameter of the vertical section increased from 600 mm to 1000 mm to reduce the up-flow steam velocity but without success. Satisfactory operation could not be achieved until the inflow was tangential and sloped 30° downward as shown in Figure 2.

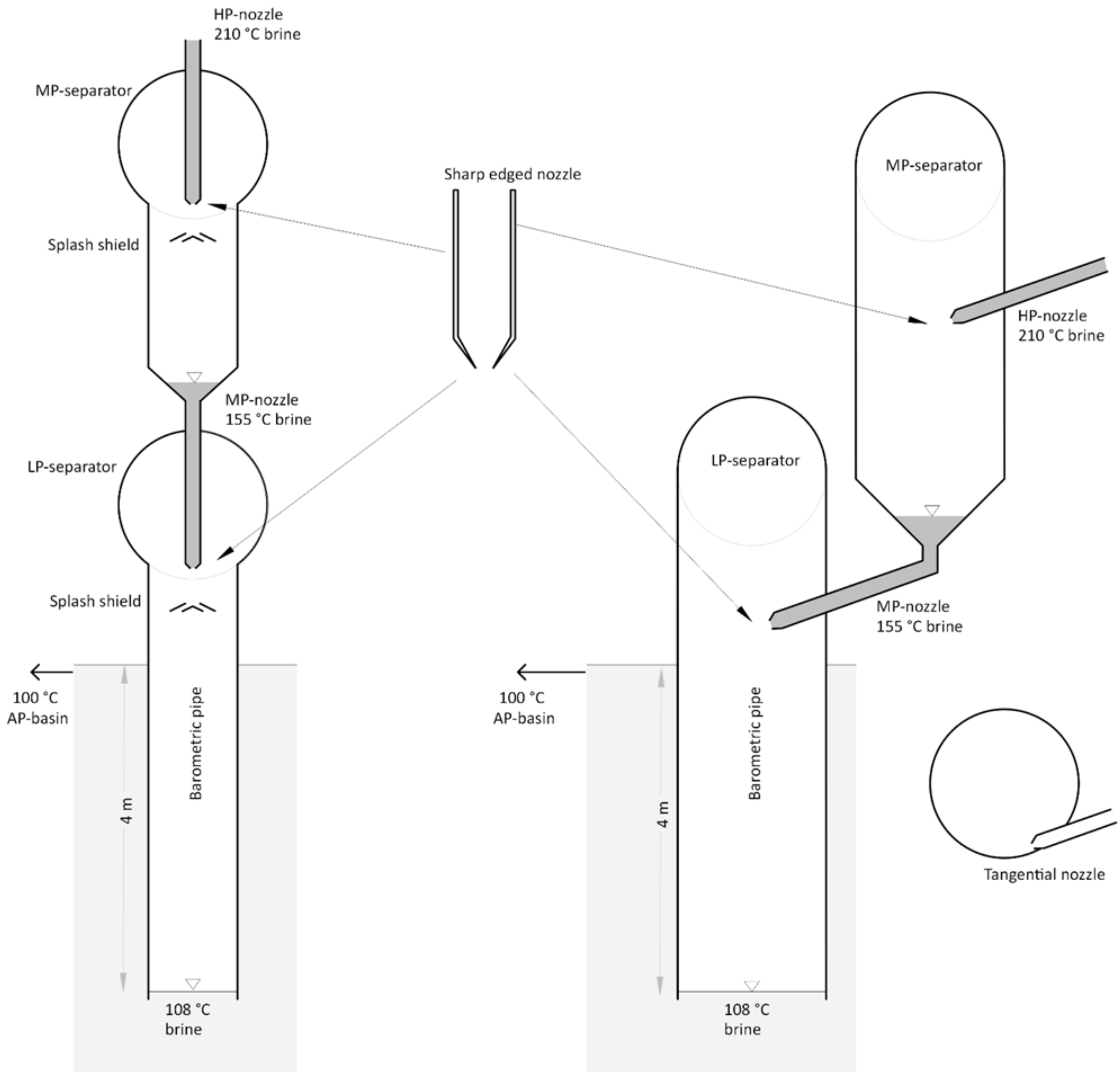

Figure 2: Cross sections of experimental two stage separator. Initial set up to the left and final modified setup to the right.

4. SCALING STUDIES

One of the main purposes of the experiments was to find out how the two-stage separator can be operated with minimal scaling. It was clear from the first test run that the scaling would be manageable in a properly designed nozzle separator. Further test runs confirmed this. Each test run lasted for 14 days and the scaling thickness was measured in the end and samples collected for analysis. When the flow in the separators was under control, by using tangential nozzles, minimal scaling in the horizontal section could be achieved.

4.1 MP-separator

In the inlet nozzle to the MP-separator fibrous scale of metal sulfides and metal silicates formed, similar to the scale in the HP-separators of the Reykjanes plant. The scale adhered to the inside of the nozzle, see Figure 3. Investigation in an electron microscope (SEM) showed fibrous scale, which contained lead, zinc, silver, copper and iron sulfide and silicate, see Figure 4. The flow restriction was negligible because of the sharp-edged lip of the nozzle. Scaling rate was also low inside the vertical section of the MP-separator, especially were the two-phase flow from the nozzle hit the surface, see Figure 5.

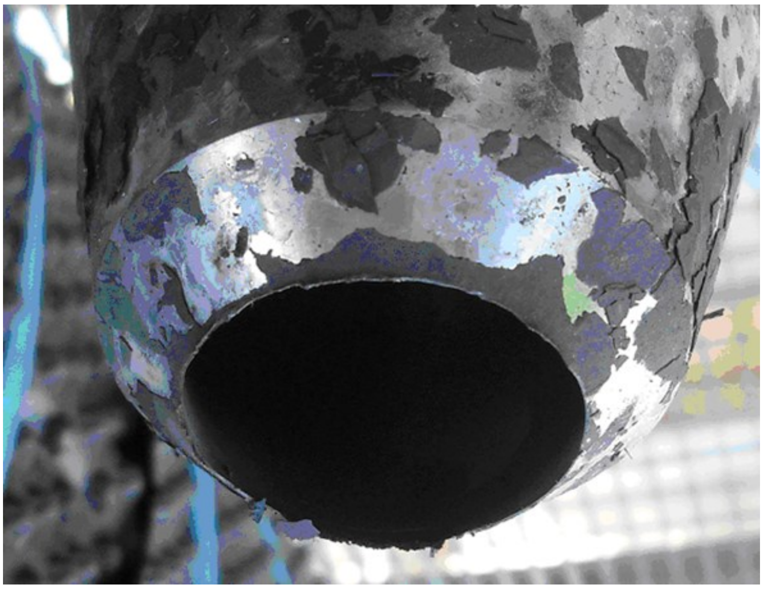

Figure 3: Inlet nozzle to the MP-separator after 14 days.

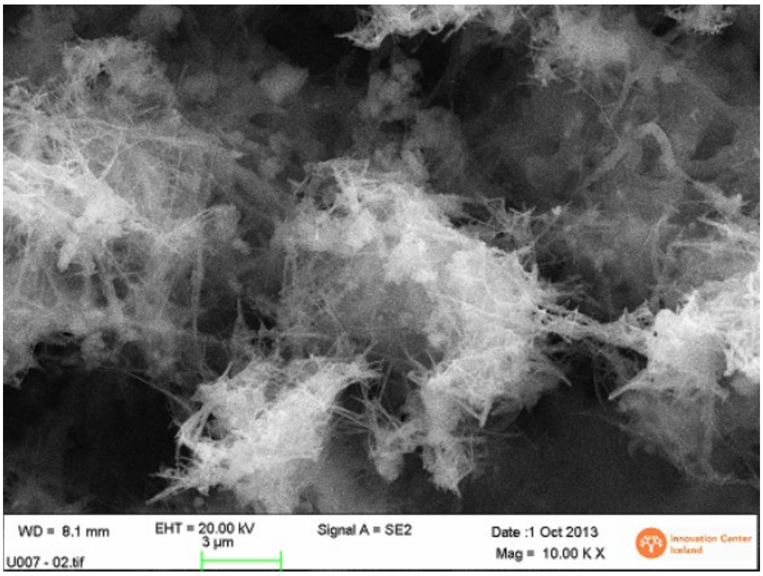

Figure 4: Fibrous scale in the inlet nozzle to the MP-separator.

Figure 5: MP-separator outlet pipe after 5 months operation.

4.2 LP-separator

Two types of inlet nozzles to the LP-separator were tested. A nozzle with sharp edges and a flat end nozzle. The sharp-edged nozzle worked better because the scale broke off in the critical flow in the nozzle lip. The scaling inside inlet nozzle to the LP-separator was very hard and the rate of formation was 26 mm per year and it gradually restricted the flow (Figure 6). Regular cleaning of the nozzle to maintain full flow will therefore be required by drilling. A sample of the scale was investigated in an electron microscope and it had grainy texture and contained small particles of 0.1 µm. It was made of 90% silica (SiO_2) and the remaining constituents were lead, zinc, copper and iron sulfide and silicate (Figure 7).

Scaling rate above brine level in the barometric outlet pipe from LP-separator was 30 to 40 millimeters per year (Figure 8). This is manageable scale in the wide pipe. Below the brine level in the pipe the scaling rate accelerates and was as high as 700 mm per year, see Figure 9. This scale is soft and can be easily removed. By keeping the level in the outlet pipe as close to the rim as possible this scale can be minimized. The scale was 100% amorphous silica and made of large spheres of 1 to 2 µm diameter (Figure 10).

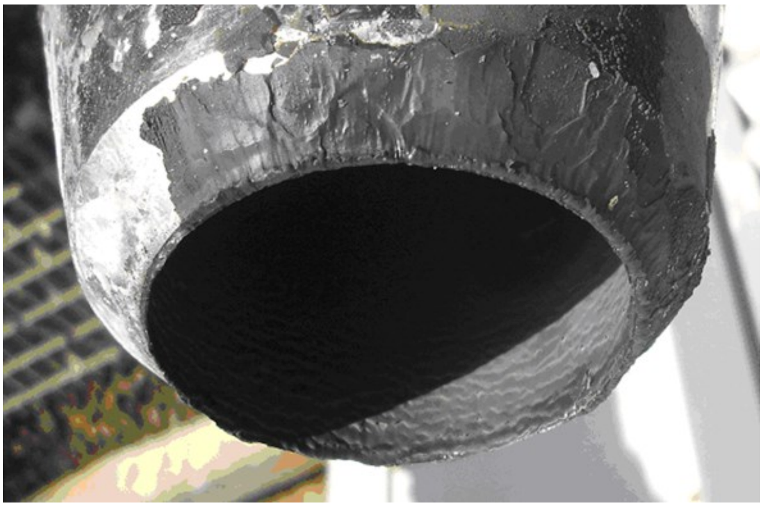

Figure 6: Inlet nozzle to the LP-separator after 14 days.

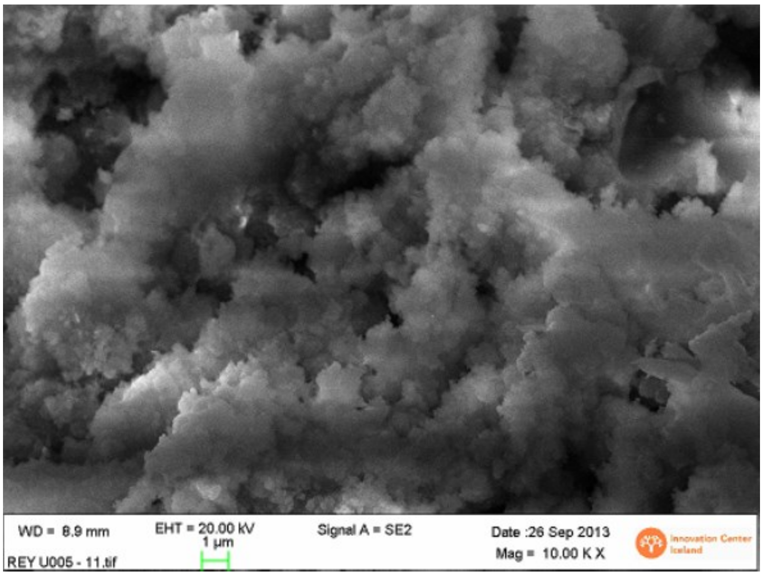

Figure 7 Grainy scale in MP-nozzle.

Figure 8: Barometric outlet pipe from LP-separator after 5 months.

Figure 9: Soft silica scale below brine level in barometric pipe.

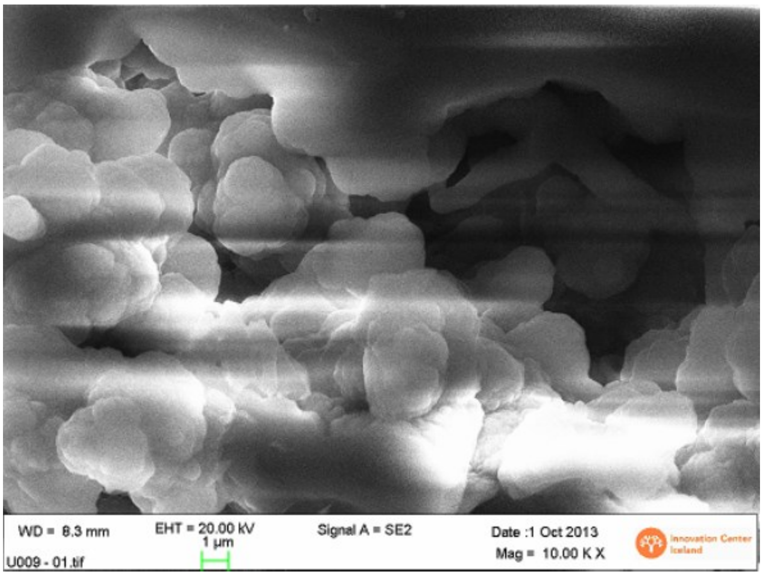

Figure 10 Amorphous silica spheres 1 to 2 µm in LP-outlet pipe.

4.2 AP-separator basin

When the brine entered the open basin, precipitation of silica was very rapid and pure amorphous silica sludge made of very fine grains was formed. The silica partly settled and accumulated in the basin but was also suspended in the brine and carried along with the effluent flow. This needs to be taken care of in final process design to avoid accumulation of silica sludge in the basin which may obstruct the flow. Separate study was therefore conducted to gain information on how the silica settling in the outlet could be controlled in a precipitation reactor and clarifier. This study is described in separate paper at this convention, Hauksson et al. (2020).

5. NOZZLE DRILL

A drill for reaming the nozzles was designed and built. It was hydraulically driven and was inserted into the nozzle through a pressure tight insertion and removal mechanism. The drill could easily remove the hard scale inside the nozzles with the drill bits made of carbide, see figure 11.

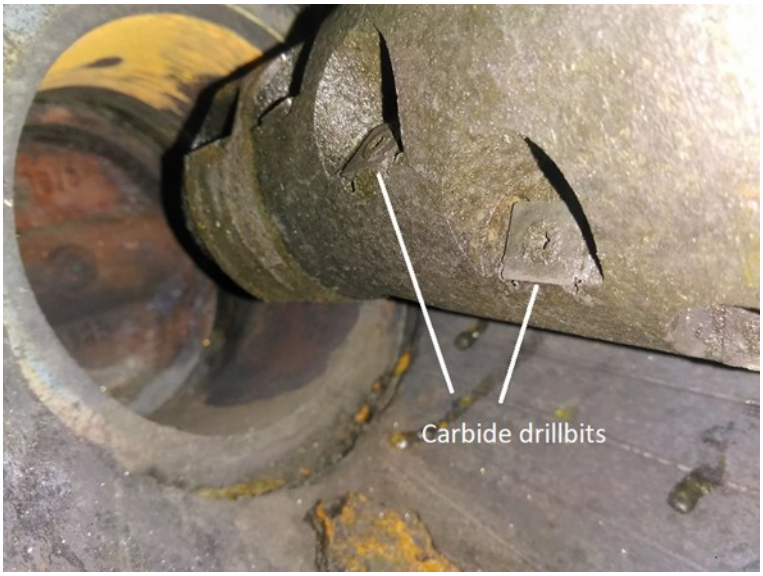

Figure 11: Drill for reaming the sharp-edged orifices.

6. CONCLUSION

The experiments confirmed that by using critical nozzle separator the silica scale can be controlled successfully without any chemical use. The scaling is manageable and the separators can be operated continuously for several months by using a nozzle drill for reaming the nozzles in operation. Full-size separators are being designed, based on these experiments.

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