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Prevention of Corrosion and Scaling in Geothermal Power Plants Equipment

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ABSTRACT

Problems of the metal erosion-corrosion processes and the formation of deposits during operation of a geothermal power station are analyzed. Methods for preventing the formation of deposits and making the geothermal power station equipment more resistant to erosion and corrosion are considered. Results from calculation and experimental investigations aimed at studying how the concentration of silicic acid and other admixtures vary in the working loop and turbine flow path at the Verkhne-Mutnovsk geothermal power station are presented. The possibility of using surface-active inhibitors to prevent the formation of deposits and erosion–corrosion processes in the geothermal power station equipment is demonstrated.

1.INTRODUCTION

Exploitation of Geothermal Power Plants (GeoPP) is usually accompanied by corrosion damages and formation of scale deposits in the pipelines and power equipment, leading to the reliability and efficiency reduction.

Prevention of corrosion and scaling on GeoPP is an important practical problem. On the basis of the practical experience and analytical investigations elements of high wear for pipelines and power equipment of Mutnovsky GeoPP (50 MW) and Verkhne-Mutnovsky GeoPP (12 MW) have been detected.

The technology of surface-active reagents periodic dosing in the pressure circuit of a geothermal power plant during its operation (in order to prevent corrosion and scaling) and at the shut-down (to protect against atmospheric corrosion) has been developed. Analysis of the first results of these technologies implementation on the Russian GeoPPs fully confirmed their effectiveness both in single and two-phase flows.

The specific features relating to the chemical composition and thermophysical properties of geothermal heat carrier give rise to certain problems during operation of geothermal power stations (GeoPPs) connected with damage to metal and formation of deposits.

2. THE EROSION-CORROSION AND FORMATION OF DEPOSITS DURING OPERATION OF A GEOTHERMAL POWER STATION

More than 70% of GeoPPs installed around the world, including those in Russia, operate on a two- phase (wet-steam) heat carrier, Tomarov, Nikol’skii et al. (2012). Owing to interphase redistribution of substances, the major part of admixtures and salts is in the liquid phase and non-densables are contained in the vapor phase.

The phase state of the geothermal working fluid and the concentration of admixtures and nondensables taken in combination with the flow hydrodynamics and the erosion—corrosion properties of metal are the factors that determine to a considerable degree the possible occurrence and intensity of damage inflicted to Geo PS components, as well as the formation of deposits on the surfaces of equipment and pipelines. The scheme shown in Fig. 1 reflects the influence of admixtures and gases on the occurrence of different mechanisms through which damage is inflicted to metal and on the formation of salt deposits in single- and two-phase geothermal heat carriers. Some methods for preventing the occurrence of these undesirable phenomena at GeoPPs are also shown in this figure. It has been found that the physicochemical properties and the concentration of admixtures and nondensables determine the location of zones and intensity of erosion—corrosion thinning and formation of deposits in the working loop, and that they have an effect on the metal corrosion and cracking processes in the GeoPP equipment, Semenov et al. (2002). The mechanisms of droplet impingement and cavitation erosion depend on them to a lesser extent.

An analysis of the problems encountered during operation of the Mutnovsk GeoPP with a capacity of 50 (2 x 25) MW and the Verkhne-Mutnovsk GeoPP with a capacity of 12 (3 x 4) MW, Tomarov, Parshin et al. (2012) testifies that erosion—corrosion thinning and stress corrosion cracking of metal are the main factors that caused abrupt fractures and failures of the equipment and pipelines of these GeoPPs, and that the formation of deposits degrades their performance efficiency.

Rapid clogging of the Mutnovsk GeoPP turbine flow paths with deposits and damage inflicted to them due to erosion—corrosion processes have led to the need to shorten the intervals of time between repairs: medium repairs are carried out once in two years, and overhauls once in four years. Repair works are mainly aimed at removing deposits and restoring (or replacing) the turbine unit flow path components susceptible to erosion—corrosion. For example, in 2008, the costs for the overhaul of the Mutnovsk GeoPP turbine generator No. 1 totaled more than 3 million rubles and those for repairing the rotor around 6 million rubles. The extent of erosion—corrosion damage is so significant that a full-scale repair or replacement of the turbine rotor is required already after 5—6 years of its operation.

The overall economic losses connected with the formation of deposits and erosion—corrosion of metal at the Mutnovsk GeoPP comprise the costs for measures taken to remove the consequences and prevent the occurrence of the above-mentioned problems and the costs connected with underproduction of electricity due to failures and disconnection of equipment, forced outages, and degraded efficiency of the power station as a whole. As a result, the annual economic losses per GeoPP power unit may total tens millions of rubles.

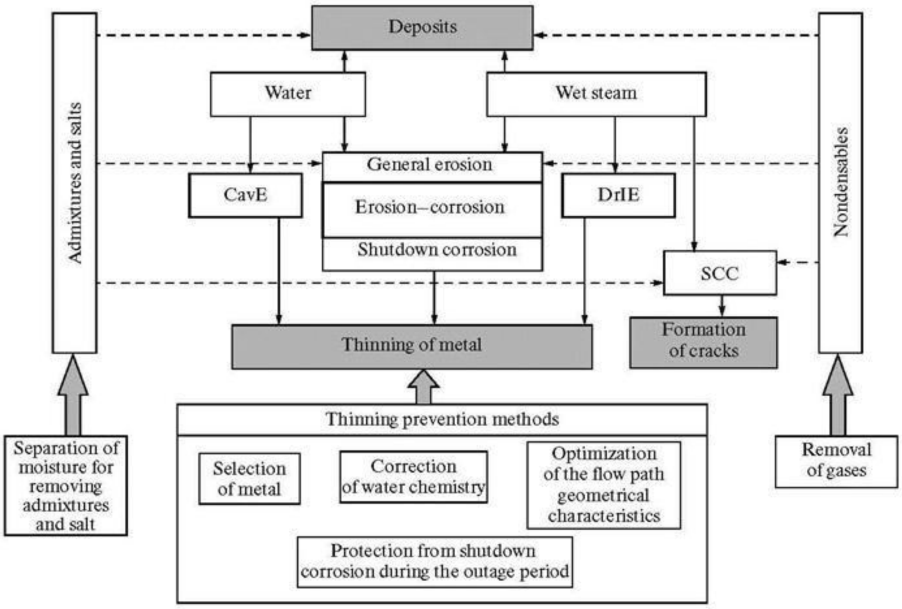

Figure 1: Problems concerned with damageability of metal and formation of salt deposits in single - and two-phase geothermal heat carriers and methods for preventing damage to elements of GeoPP pipelines and equipment. CavE is cavitation erosion, DrIE is droplet impingement erosion, and SCC is stress corrosion cracking.

Before admixtures and salts precipitate as deposits on the working surfaces of the turbine flow path and other GeoPP equipment, they should accumulate in heat carrier in the georeservoir and then be subjected to different sorts of transformations and effects as the heat harrier moves over the working loop, including phase conversions, concentration, coagulation, and sedimentation on the metal solid surface. Figure 2 illustrates the conditions under which the above-mentioned processes take place and the specific features relating to these processes with participation of admixtures and salts in the GeoPP process path.

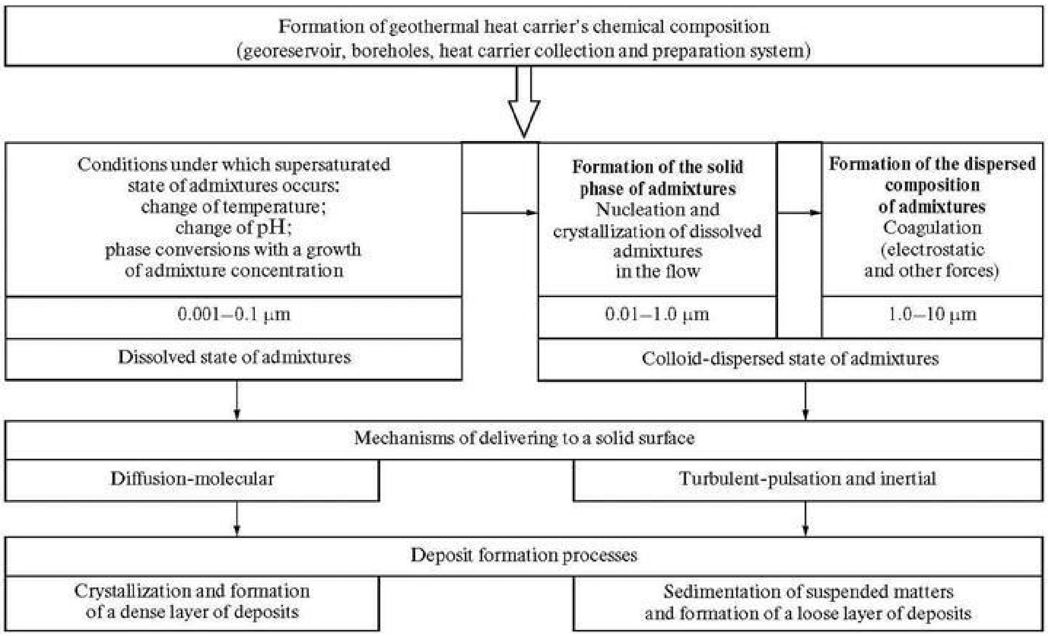

Figure 2: Conditions, mechanisms, and processes relating to the behavior of admixtures in the GeoPP working loop.

Silicic acid contained in a geothermal heat carrier is one of the main components of deposits precipitating in the equipment flow path at the GeoPPs in Kamchatka; therefore, data on its concentration are necessary for analyzing the deposit formation processes and their rate. In practice, it is not always technically possible and economically feasible to obtain information about the concentration of silicic acid and other admixtures in heat carrier at different points of the GeoPP process loop that affect the metal erosion- corrosion process. In particular, this is connected with difficulties of ensuring representativeness of working fluid samples, especially in a two-phase wet-steam flow of geothermal heat carrier. In view of this fact, the use of calculation methods for determining the change in the content and concentration of admixtures along the GeoPP process loop is a topical problem, and the results of its solution may become a basis for elaborating methods and measures for predicting and preventing erosion—corrosion and deposit formation phenomena.

3. RESULTS CALCULATION AND EXPERIMENTAL INVESTIGATIONS AIMED ADMIXTURES IN THE VERKHNE-MUTOVSK GPP

An analysis model called the V-M GeoPP Loop constructed on the basis of thermal and material balances taking into account the specific features pertinent to phase conversions of working medium and interphase redistribution of substances was developed for estimating the concentrations of silicic acid and other admixtures in the liquid phase of the wet-steam heat carrier and separated moisture in the working loop of the Verkhne-Mutnovsk GeoPP. By using this computer program, it is possible to calculate the concentration of chlorides, silicic acid, iron, and other chemical compounds in the steam and liquid phases of geothermal heat carrier at different points of the Verkhn-Mutnovsk GeoPP working loop.

The basic process circuit of the Verkhne-Mutnovsk GeoPP with indication of calculated points is shown in Figure 3. The following actual values of initial data were adopted in the calculations:

Steam—water mixture from the production well:	
pressure, MPa	0.8
humidity, %	70
flowrate,t/h	115
Steam humidity at the separator outlet, %	
the first stage	0.05
the second stage	0.01
Steam parameters at the turbine outlet:	
pressure, kPa	11
final humidity, %	12
Steam parameters at the evaporator outlet:	
pressure, MPa	0.4
humidity, %	0.05
Bulk concentration of substances in the geothermal heat carrier at the production well outlet, ppm:	
iron	23
silicic acid	560
chlorides	154
Concentration of octadecylamine at point 1 (Figure 3), ppm	10

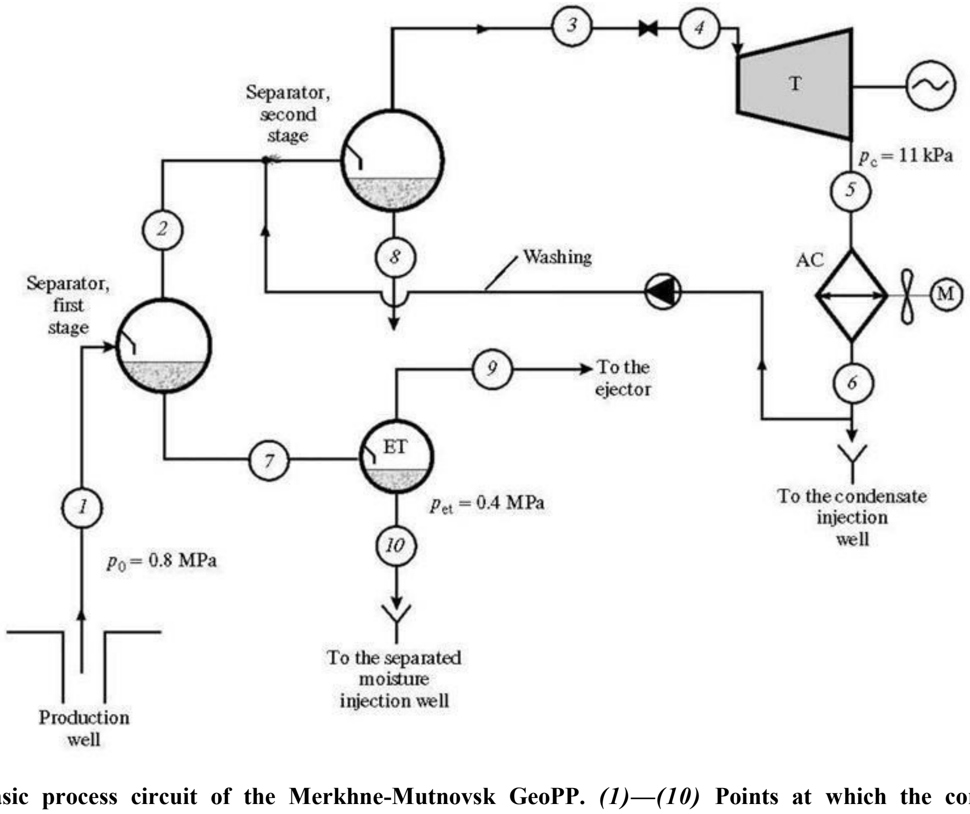

Figure 3: Basic process circuit of the Merkhne-Mutnovsk GeoPP. *(1)—(10)* Points at which the concentrations of admixtures in the vapor and liquid phases arc calculated. ET is an expansion tank, AC is an air condenser, M is a motor, p_0 is the pressure at the borehole mouth, p_{et} is the pressure in the expansion tank, and p_c is the pressure in the condenser.

The calculations were carried out on the assumption that the dissolved substances entering into the GeoPP working path with the geothermal heat carrier do not come in interaction and do not precipitate in the loop. The interphase redistribution coefficients of silicic acid, chlorides, and iron are much smaller than unity; this is why they are redistributed into the liquid phase. In what follows, calculated data on the concentration of silicic acid in the loop are considered taking this fact into account.

The variation of calculated silicic acid concentrations in the heat carrier's liquid phase estimated at ten points of the Verkhne-Mutnovsk GeoPP loop (Fig. 4) testifies that a considerable portion of its content is removed first with the moisture separated in the first wet steam drying stage (point 7) and then with the moisture separated from the evaporator (point *10)* to the reinjection well. This may lead to formation of deposits in the reinjection system. Dark points in Fig. 6 show the bulk concentration of silicic acid in single- and two-phase heat carrier in different places of the Verkhne-Mutnovsk GeoPP working loop. It can be seen that, with the silicic acid concentration in the wet steam liquid phase at the turbine inlet (point *4)* equal to around 800 ppb, its bulk concentration in the two-phase flow will be equal to 0.1 ppb. In addition, similar data from experimental measurements of silicic acid content in the flow are shown for points 3, 7, and 10, which are in good agreement with the calculated results.

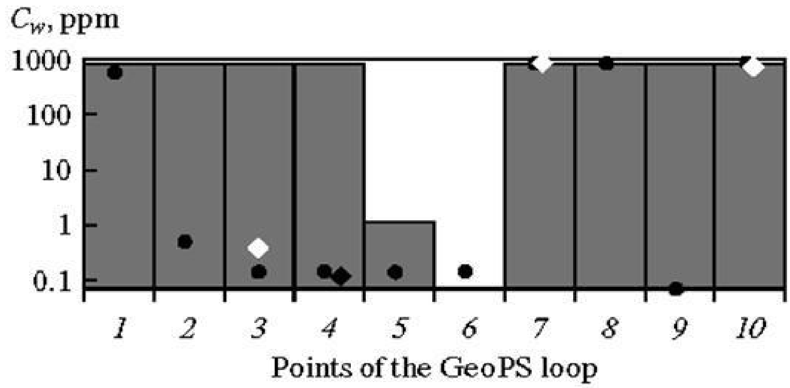

Figure 4: Results of numerical investigations on studying the variation of silicic acid concentration C_w in the liquid phase of geothermal heat carrier circulating in the Verkhne-Mutnovsk GeoPP working loop. *(1)-(10)* Points of the GeoPP working loop for which samples were taken and numerical studies were carried out, (•) calculated values of the bulk concentration of silicic acid in single- and two-phase heat carriers, and (◊, ♦) experimental data from silicic acid concentration measurements in the flow of heat carrier at the Verkhne-Mutnovsk and Mutnovsk GeoPPs.

The results of calculations carried out for the turbine flow path show (Figure 5a) that the silicic acid concentration drops from stage to stage due to its dilution by the moisture of condensing steam. The high concentrations of chlorides in the working medium's liq-uid phase that are observed in the turbine first stages (Fig. 5b) are able to provoke stress corrosion cracking of metal for rotor elements and rotor blades.

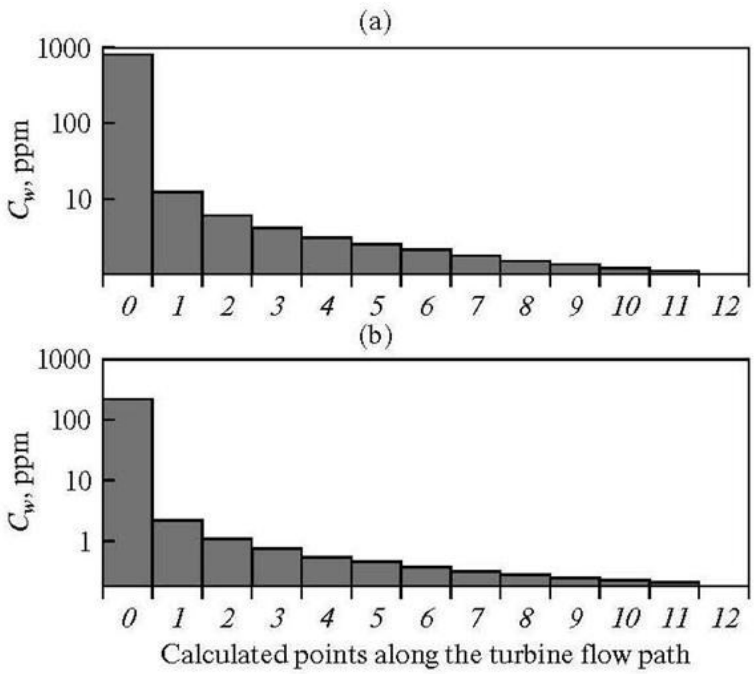

Figure 5: Calculated concentrations of silicic acid Cw (a) and chlorides (b) in the liquid phase of working fluid in different flow path stages of the turbine at the Verkhne-Mut-novsk GeoPP.

Considerable concentrations of silicic acid in the liquid phase in the GeoPP turbine first stages (up to 5— 12 ppm, see Figure 5) are conductive to clogging of their flow path. Since the Verkhne-Mutnovsk and Mutnovsk GeoPPs use geothermal heat carrier from the same field, the problems connected with formation of deposits in their turbines are similar, and field experience confirms this statement.

Table 1 presents experimental data on the amount and chemical composition of deposits in the first stages used in the flow path of Unit 1 turbine at the Mutnovsk GeoPP. The deposits consist mainly of silicon and sulfur oxides and have only a small quantity of iron-containing compounds.

Table 1: Chemical composition and amount of deposits in the turbine flow path components of the Mutnovsk GeoPP Unit 1 (as of September 2005)

Component	Mass of deposits, g	Content of, %						
		Na_2O	K_2O	Fe_2O_3	SO_3	SiO_2	Cl	NH_4
1st stage nozzle vane cascade	38.9	0.28	0.09	0.02	3.83	92.37	0.25	0.02
1st stage rotor bucket	1.4	0.53	0.11	0.09	2.62	72.28	0.10	0.20
2nd stage rotor bucket	2.5	0.07	0.04	0.04	0.05	42.58	2.91	0.43
3rd stage rotor bucket	3.3	0.34	0.05	0.60	59.79	4.00	0.0	0.02

4. USING OF SURFACE-ACTIVE INHIBITOR TO PREVENT THE DEPOSITS AND THE EROSION-CORROSION

A method involving periodic metering of surface- active inhibitor (for example, octadecylamine) into the geothermal heat carrier during power plant operation may become an efficient means to prevent the formation of deposits, to wash them out, and to slow down the erosion—corrosion rate of the metal of the GeoPP turbine flow path and the station's entire process loop. The physicochemical properties of this substance with regard to washout of deposits, removal of chlorides from microcracks, inhibition of corrosion (shutdown corrosion included) and reduction of hydraulic losses, which have been confirmed many times by field experience in traditional and nuclear power engineering, and an analysis of study results, Tomarov, Parshin et al. (2012) and Povarov (2002) and give us grounds for developing a method of achieving better resistance of metal to erosion—corrosion and for putting it in use at Russian GeoPPs.

The results obtained from calculation studies carried out using the V-M GeoPP Loop model have shown that the liquid phase contacting with the working loop metal surface (Fig. 6a) and in the turbine flow path (Figure 6b) contains octadecylamine in concentrations of 2—5 ppm, which are sufficient for realizing its inhibiting properties.

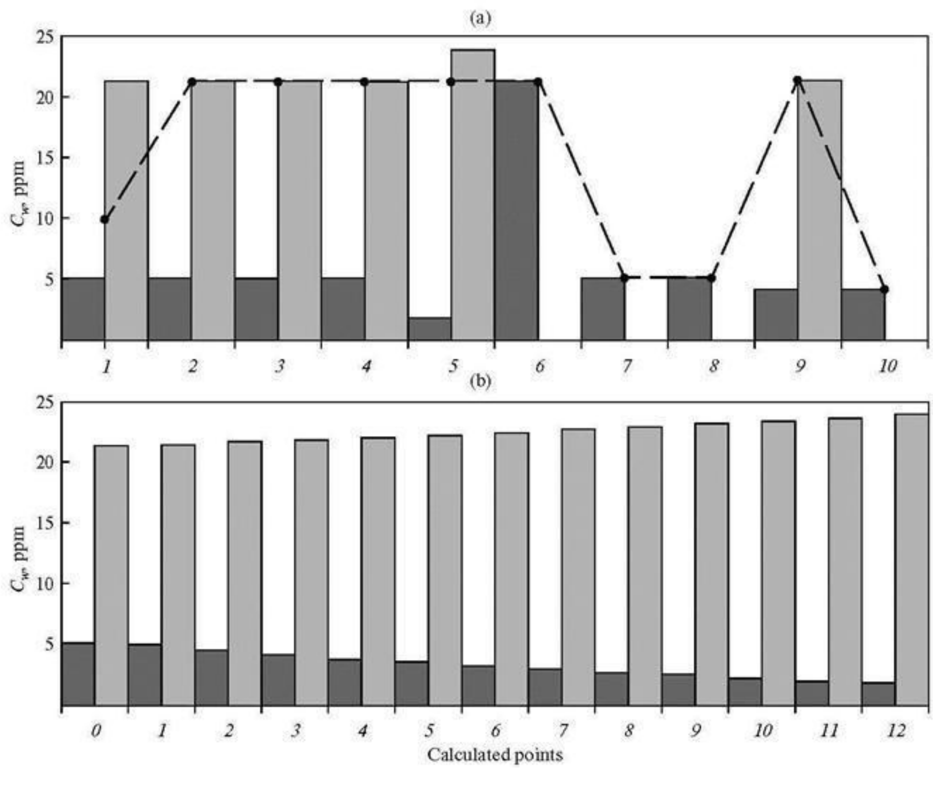

Figure 6: Calculated concentrations of octadecylamine in the steam and liquid phases of geothermal heat carrier at the Verkhne-Mutnovsk GeoPP (with the octadecylamine concentration at the inlet to the first-stage separator equal to 10 ppm). (a) In the working loop and (b) in the turbine flow path stages. (,) Steam and liquid phases, respectively; and (•) experimental data.

Promising technology is the adjustment of geothermal coolant water chemistry by surface-active additives, which can control the physical and chemical properties of geothermal fluid. As the result of this Technology implementation on Mutnovskaya GeoPP the positive effects are expected among which:

Removing and preventing the formation of deposits in pipelines, turbines, separators and other power equipment due to the detergent effect, increasing the pH values and hydrophobic surface creation;

Reducing the intensity of Geothermal Power Plant metals general corrosion (by the inhibitory effect of surfactants, surfactant protective films on metal creation and increase the pH of geothermal fluids);

Reducing the intensity of metals erosion-corrosion for Geothermal Power Plant pipelines and equipment (by the inhibitory effect of surfactants and reducing hydrodynamic influence due to hydrophobic surfaces and reduce the value of the geothermal medium surface tension).

Prevention of stress corrosion cracking of metal disks and turbine rotors (due to the removal of chlorides from microcracks in the metal);

Reduction in the intensity of cavitation erosion of pumps, orifices and regulating valves (by reducing the surface tension of the working environment and the inhibitory effect of surfactant);

Prevention of droplet impingement erosion of turbine blades (by reducing the modal size of the disperse moisture due to the reduction of surface tension of geothermal medium)

Figure 4 shows the influence of the basic positive effects from the use of above mentioned technology on various mechanisms of metals damage. In its turn, the reduction of damage and removal of deposits in the geothermal power plant working circuit leads to improvement in important technical indicators:

• increase in the relative internal efficiency of the turbine;

• reduction of the hydraulic losses in the pipelines and power equipment;

• reducing the pressure in the condenser;

• increase the separation capacity of the separator (i.e. the decrease in the moisture content at the outlet of the separator);

• extending the service life of equipment and pipelines GeoPP.

CONCLUSION

1. By using the developed V-M GeoPP Loop model it is possible to determine the concentration of admixtures and salts in the liquid and vapor phases of geothermal heat carrier at different points of the process loop taking the GeoPP operating conditions into account.

2. The results of calculations carried out using the V-M GeoPP Loop model may become a basis for performing qualitative assessments of the possibility of occurrence and rate of deposit formation mechanisms in the GeoPP process loop in different modes of power plant operation.

3. The results of calculated studies testify that it is possible to obtain the necessary concentrations of octadecylamine in the liquid phase of geothermal heat carrier for ensuring its washout and inhibiting properties in the GeoPP' entire process loop.

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