

Experience of using the NALCO 1392 scale inhibitor in the circulating water supply system of the Novovoronezh NPP*

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Abstract

Power facilities use large amounts of water to cool steam in the steam turbine condensers, and lubricating oils, gas and air in turbine sets. The key requirement for the quality of cooling water is to ensure normal vacuum in condensers. Cooling water must not form mineral and biological deposits and corrosion products in the system. Deposits of mineral salts in the condenser tube system, as well as in auxiliary cooling systems, lead to deterioration in heat exchange and a major decrease in the cost effectiveness of the power equipment operation, and require the heat-exchange equipment to be periodically cleaned. The source water used for cooling is normally taken from nearby water bodies (large rivers or lakes). Circulating water supply systems are used most commonly: these systems use repeatedly the same water inventory for cooling, and require only small amounts of water added to make up for evaporation losses. Coolers, in this case, are cooling towers, spray pools and evaporation ponds. The water chemistry should ensure the operation of equipment without any damage to its components or the loss of efficiency caused by the corrosion of the internal surfaces as well as without scale and sludge formation. It is exactly when using circulating water supply that a stabilizing treatment program is the most practicable way to ensure a cost-effective and environmentally friendly mode of operation. To inhibit scaling processes on the heat-exchange surfaces of the turbine condenser tubes at the Novovoronezh NPP's unit 5, the cooling water was treated with the NALCO 1392 inhibitor. The results of the NALCO 1392 inhibitor pilot tests in the circulating water supply system (with a cooling pool) are presented.

Keywords

Scale formation processes, circulating water supply system, scale inhibitor, NALCO 1392

Introduction

In the process of operating the circulating water supply system at the Novovoronezh nuclear power plant (NVNPP),

heating leads to the cooling water oversaturation with salts, primarily, with calcium carbonate, this causing the formation of scale on the heat-exchange surfaces (Vlasova 2007, Vitkovskiy et al. 2017). The presence of scale and

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deposits deteriorates the heat exchange and reduces the efficiency of the equipment operation which entails bigger economic losses.

Internationally, acidification of makeup water, which is a costly process, is used to eliminate the causes for the calcium carbonate deposition on the heat-exchange equipment (Golovatenko 2018, Galanin et al. 2019). An alternative way to cope with the negative effects of the high carbonate hardness of water is to maintain such water chemistry in the system with which the scale crystals formed are stabilized within the water column by the action of the salt scaling inhibitor and do not settle on the heat-transfer surface (Ivanova and Cherkasova 2016, Procedural recommendations).

The deposition rate of low-solubility salts on the heat-exchange surface depends on the quality of the source water, the oversaturation value, the inhibition method, heat flux densities, etc. (Kishnevsky and Chichenin 2014). In particular, the formation of deposits consisting of calcium carbonate is affected by the content of total hardness and total alkalinity in the cooling water, and the cooling water temperature.

To increase the solubility limit for hardness salts and to modify the structure of the crystals formed, an inhibitor based on modified phosphonic acid, Nalco 1392, (Table 1) was fed into the circulating water supply system at unit 5 of the Novovoronezh NPP in August 2018 through June 2019.

Table 1. Main physicochemical properties of the Nalco 1392 inhibitor

Form	Liquid
Color	Transparent
Odor	Minor
pH	0 to 2.1 units
Freezing temperature	-15 °C
Relative density	1.32 g/cm ³

There are three mechanisms in which scale inhibitors act on the crystallization process of low-solubility salts from supersaturated aqueous solutions:

- the inhibitor, as it adsorbs on the surface of the developed crystal nucleus (crystallization process), prevents this from growing further (the so-called threshold mechanism or stabilization of the supersaturated solution);
- the inhibitor, as it adsorbs on the actively growing crystal surface and on the crystal lattice defects, stops or slows down the crystal growth, and can also modify the crystal lattice (inhibition of the crystal growth);
- the inhibitor, as it adsorbs on the crystal surface, prevents the crystals from interacting with each other and aggregating into homogeneous deposits (a dispersion mechanism).

Scale inhibitors exhibit three mechanisms of action simultaneously (Agazadeh et al. 2019).

It needs to be noted that the surfaces of the turbine set (TS) condenser tubes were cleared of carbonate deposits prior to the reagent treatment using various techniques:

- the tubes in TS-14 were treated chemically and hydro-mechanically;
- the condenser in TS-13 was treated only hydromechanically.

In this connection, the condition of the TS-13 and TS-14 condenser tubes was different at the initial stage which needs to be taken into account when analyzing the results since the “older” deposits, which have not been removed in full, act as the crystallization centers and reduce, therefore, the efficiency of treatment.

The working concentration of the reagent in the cooling water was maintained by feeding continuously into the suction chambers of the circulating pumps a solution with a flow rate of 3 to 6 l/h.

Fig. 1 presents diagrams showing the change in the total hardness of the cooling water and the content of the Nalco 1392 reagent.

The total hardness of the cooling water varied between 5.0 and 7.2 mg-equ/l which corresponds to the values adopted for the inhibitor dose calculation. An increase in the concentration of the reagent at the end of the test period is most likely caused by its accumulation in the system.

Total hardness of water is the sum of the molar concentrations of the calcium ($1/2 \text{ Ca}^{2+}$) and magnesium ($1/2 \text{ Mg}^{2+}$) ion equivalents in water. The total hardness value is measured by complexometric titration which is based on the capacity of calcium and magnesium ions to form complex compounds with certain dyes, specifically, with dark-blue chromium indicator. The strength of these complexes is much smaller than the strength of calcium and magnesium cation complexes with Trilon B, so adding a solution with Trilon B to indicator-dyed solutions, containing calcium and magnesium ions, destroys these while restoring the color of the free indicator (STO 1.1.1.07.003.0727-2014).

Fig. 2 shows the dynamics of the change in the calcium ion content in the cooling water at the TS 14 condenser inlet and outlet.

As follows from the figure, the concentrations of calcium ions at the condenser inlet and outlet in the period under consideration are equal which indicates indirectly that no insoluble calcium compounds form. In the event of calcium passing into an insoluble form and calcium carbonate forming, there would be a reduced content of calcium observed in water at the condenser outlet.

Such integral indicator of heat transfer as the condenser temperature head, which is determined using formula (MU 1.2.1.16.0104-2012), was used as the parameter defining the trend of the mineral deposit formation on the condenser tubes (MU 1.2.1.16.0104-2012)

$$\delta t = t_s - t_{cw},$$

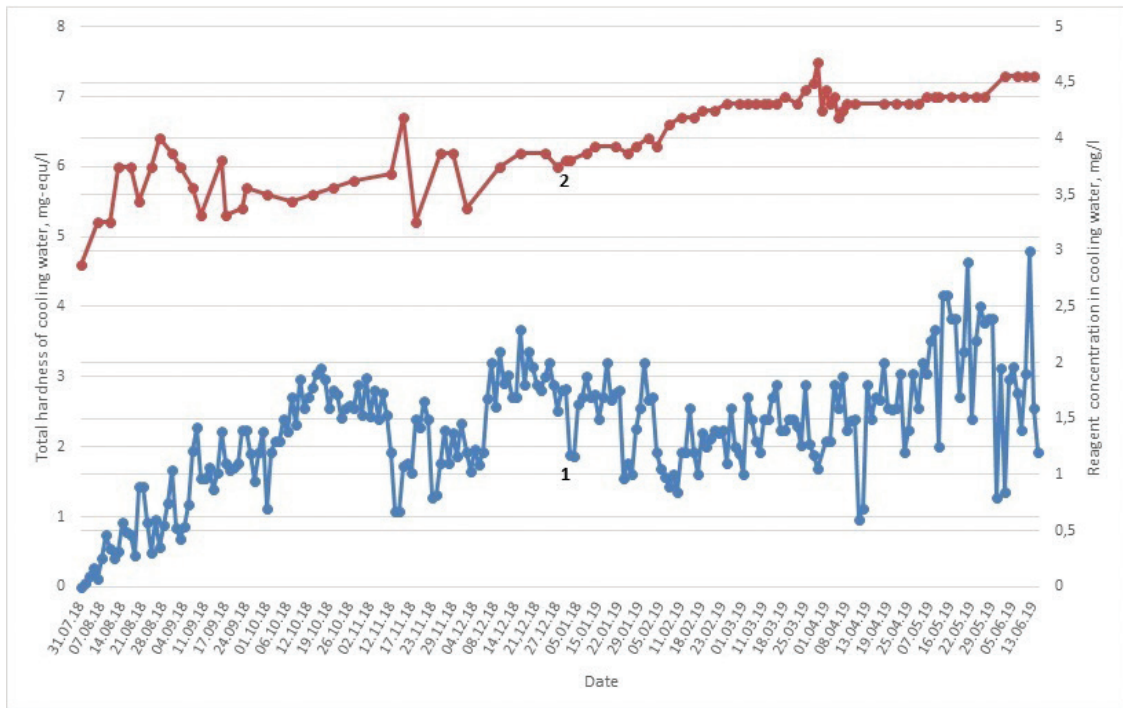


Figure 1. Change in the concentration of the NALCO 1392 reagent and the total hardness of the cooling water: 1 – NALCO 1392 concentration in water; 2 – total hardness of the cooling water



Figure 2. Content of calcium ions in the cooling water at the condenser inlet and outlet: 1 – concentration of calcium ions at the TS-14 condenser inlet; 2 – concentration of calcium ions at the TS-14 condenser outlet

where t_s is the saturation temperature of spent steam in the condenser, °C, corresponding to the actual absolute pressure of steam in the condenser; and t_{cw} is the actual temperature of the cooling water at the condenser outlet, °C.

The standard value of the spent steam absolute pressure is determined from the standard characteristic of the condenser with the actual values of the cooling water temperature, the steam flow rate into the condenser, and the cooling water flow rate in the period under review. For a turbine with the condenser sections serially connected for

cooling water, the actual and standard values of the absolute spent steam pressure are determined individually for each section, and the root-mean-square pressure values for individual sections are written down for the condenser as the whole (MU 1.2.1.16.0104-2012).

Temperature head of a condenser (as of practically any heat exchanger), just like total heat-transfer coefficient, is the fullest and versatile criterion of the efficiency of the process of heat transfer from spent steam to cooling water. It should be taken into account that, unlike heat-transfer coef-



Figure 3. Temperature head change for the TS – 13 condenser: **1** – temperature head in 2016–2017; **2** – temperature head in 2017–2018; **3** – temperature head in 2018–2019



Figure 4. Temperature head change for the TS-14 condenser: **1** – temperature head in 2016–2017; **2** – temperature head in 2017–2018; **3** – temperature head in 2018–2019

ficient that can be obtained not by direct measurements but just by calculations, temperature head is rather easy to determine and is therefore broadly used in operation. Inlet cooling water flow rate and temperature, as well as steam flow rate are taken into account primarily in the temperature head calculation for a particular turbine set (Ilyenko et al. 2006).

The temperature head of a condenser is affected practically by all major factors that characterize the operating

conditions and the state of individual condensation plant components: steam demand, temperature and flow rate of cooling water, air tightness of the vacuum system, state of the tube surfaces, number of plugged tubes, operating efficiency of air removing devices, and others.

Fig. 3 shows changes in the temperature heads of the TS-13 condenser prior to the treatment start in 2016–2017, in 2017 – 2018, and in the treatment period (2018–2019).

As can be seen from the figure above, the reagent treatment of the cooling water undertaken in 2018–2019 had a positive effect on the TS-13 condenser temperature head change. Despite the fact that the temperature head level was higher than in the previous years (probably due the heat-transfer surfaces not cleaned efficiently enough in the preventive maintenance period), the temperature head did not practically change during the 2018–2019 fuel cycle and remained at the level corresponding to the condenser operation start after the preventive maintenance of 2018.

Fig. 4 presents changes in the temperature heads of the TS 14 condenser prior to the treatment start in 2016–2017, in 2017–2018, and in the treatment period of 2018–2019.

A reduction in the temperature head values in the test period is indicative of positive cooling water treatment results. Moreover, a temperature head reduction is observed relative to the values as recorded following the 2018 preventive maintenance.

No presence of new mineral deposits was observed on the tube surfaces during the internal inspections of

the condensers in the preventive maintenance period after the Nalco 1392 reagent application. Reduced adhesion of older deposits to the heat-transfer surface has been recorded, which is expressed in easier and faster condenser cleaning.

Conclusions

The reagent treatment of the cooling water by a scale inhibitor in 2018–2019 made it possible to limit the process of scale formation on the TS-13 condenser tubes and to reduce the TS-14 condenser temperature heads.

Raising the efficiency of treatment requires high-quality cleaning of the tube surfaces to remove carbonate deposits.

To confirm the results obtained, it is required to continue to treat the cooling water in the water supply system at the NVNPP's unit 5 with the Nalco 1392 scale inhibitor following chemical treatment and scale removal.

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