Cleaning of Thermal Equipment from Scale with Activated Water

S P Zakharychev¹, K P Pozynich¹, S V Telnova²

¹Department of Transport and Technological Systems in Construction and Mining, Pacific National University, 136, Tikhookeanskaya str., Khabarovsk, 680035, Russia
²Department of Foreign Languages, Pacific National University, 136, Tikhoweanskaya str., Khabarovsk, 680035, Russia

E-mail: kpp.51@mail.ru

Abstract. The problem of scale and corrosive action reducing the heat interchange of thermal equipment heating elements explains the ongoing search for means and methods of dealing with these phenomena. The paper analyzes the modern technology for controlling scale and corrosion, as well as nature of water activation. The possibility of reagent-free control of water properties in various technological processes by means of activation is investigated. The technology of cleaning the internal surfaces of thermal equipment and pipelines with thermodynamically (energetically) activated water is considered in detail.

1. Introduction
Reducing energy consumption and improving the efficiency of the working process is one of the areas for improving equipment and technology. Among the main factors affecting the technical and economic performance of thermal equipment is the contamination of its internal heating surfaces (formation of scale). Hard deposits that worsen the heat interchange processes are formed on the heating surfaces as a result of physical and chemical processes occurring in the aqueous medium of thermal equipment. Corrosion layer and scale increase fuel consumption, reduce reliability, efficiency and performance of heat-exchange equipment and pipelines [1]. According to statistics, the scale layer in 1 mm reduces heat interchange by 10%. In addition, the scale formation can completely block the operation of the system, lead to clogging, accelerate corrosion and cause the local overheating, burnout and rupture of boilers and pipes, which result in increased emissions of harmful substances into the atmosphere and discharges into water bodies. Contamination of the internal heating surfaces leads to an unjustified increase in operating costs associated with an increase in specific fuel consumption, energy costs for providing the specified hydraulic parameters of the heat source, as well as the cost for repairs and maintenance cleaning, which often leads to the supply cessation of technological equipment at the production facility and the population with hot water and heat, which is especially dangerous in winter. It is also important and necessary to spend money on the purchase of chemicals, repair and maintenance works regularly. This indicates the seriousness of the problem of energy and resource saving in the processes of heat supply and heat consumption, the maintenance of thermal equipment in operating condition and ensuring the modes of the heating network, since the volume of purified water and the specific energy and resource cost for protection from scale and water
treatment are very high. The problem of scale formation is pressing for the Far East of Russia, where the water used for heating networks has a high tendency to scale formation.

2. Problem statement
The reliability of Russian heat supply systems is 2.5 times lower than in European countries, 46% of underground pipelines require replacement, 70 damages are registered for every 100 km of heating networks annually [2], and the share of damage from internal corrosion is about 25% of the total damage [3]. All this is largely a consequence of the fact that traditional methods of dealing with scale on the internal surfaces of heat supply systems due to their technical and technological imperfections do not provide adequate protection of thermal equipment from scale formation and corrosion [4, 5, 6].

When water is circulating in the operating cycle of the heat exchange equipment, three main processes disrupting its normal operation can occur: scale formation, sludge formation and metal corrosion. These processes occur together, overlapping each other, therefore the scale composition and structure can vary widely, depending on the quality of feed water, pipe material, as well as temperature and hydrodynamic conditions. The formation of deposits in the form of scale or sludge is a complex physical and chemical crystallization process characterized by the release of the solid phase from multi-component supersaturated solutions, consisting of three main stages [7, 8]:

1. Achieving a state of supersaturation of scale-forming salts in water.
2. Formation of crystallization centers.
3. Crystal growth.

The most common form of scale is calcium carbonate, which most often exists in crystalline polymorphous modifications of thermally stable calcite, or metastable aragonite [9, 10, 11, 12]. Natural low-mineralized waters are characterized by their permanent components – silicon compounds [13]. The precipitation of dissolved calcium and magnesium salts occurs when water is heated and evaporated, and the precipitating salts cover the inner walls of boilers and other elements evenly with a dense and hard-to-separate crust, which is called scum [14, 15, 16] (Figure 1). The most dangerous is the viscous scale with low thermal conductivity.

![Figure 1. Scale on the inner walls of the heating network equipment.](image)

The appearance of iron oxides on the internal surfaces of thermal equipment is caused by the processes of metal corrosion and deposition of iron oxides on the heated surfaces in boiler water [17]. Currently, a variety of methods and technologies have been proposed to prevent scale formation and corrosion. They allow more or less mitigate the immediacy of the problem – mechanical, chemical and mechanical, thermal, physical, chemical, physical and chemical and their various combinations. Three main methods of descaling and deposits removal from heat exchange surfaces of thermal equipment are common:
- mechanical (hydromechanical),
- hydraulic (hydrodynamic),
- chemical (hydrochemical).

When choosing a method of prevention or preventive removal of scale, it should be considered that the effectiveness depends on the method of cleaning, as well as on the composition, properties of the removed scale, the interval of formation and the intensity of scale on the internal surfaces of the equipment.

Methods based on the physical impact on scale require partial dismantling of the equipment, so the equipment is cleaned in sections, in addition, it is difficult to clean pipelines with a complex configuration.

The process of cleaning and water treatment with reagent methods produces wastewater containing calcium chloride, magnesium, sodium and other contaminants in concentrations significantly exceeding the maximum permissible. This wastewater getting into the water bodies cause environmental damage.

Recently, the requirements of supervisory and regulatory bodies to the quality of waste water are constantly increasing. Therefore, there is a growing interest in reagent-free water treatment methods, which are not associated with the use of chemical reagents, exclude pollution of water bodies, are environmentally friendly and help to protect water heating equipment from scale.

In this regard, reagent-free water treatment technologies are being developed to improve the efficiency and safety of thermal equipment due to an increase in the anti-scale effect. To protect the equipment from scale, feed or heating-system water is subjected to the technological process of water treatment before use. This leads to a purposeful change in the objective physical and chemical properties of water due to its structural change. These include: magnetic, electromagnetic, ultrasonic water treatment technologies and the influence of electric field on water. These technologies are based on various physical principles of influence on the formed layer of scale and the process of its formation, but they all contribute to the crystallization of hardness salts in the water column and prevent crystals from reaching the sizes necessary for the formation of deposit.

Thus, activation is understood as any external action that leads to a change in the energy state of water, that is, to its "saturation" with internal energy and the method of activation is called energy (thermodynamic) [18, 19].

![Figure 2. The scheme of associates formation from monomolecular water.](image)

Features of water physical properties and numerous short-lived hydrogen bonds between neighboring hydrogen and oxygen atoms in the water molecule create favorable opportunities for the formation of special structures - associates (clusters) in the form of chains, rings, triangles and quadrangles, spirals, "poling", etc. (Figure 2), perceiving, storing and transmitting a wide variety of information. These associates make the ordinary water large-structured. But when activated, for example, heated, magnetized, vibrated or electrified, unstable water compounds break down into mono-molecules, water is "crushed", and as a result the water physical and chemical and biological activity increases. It changes its properties – density, viscosity, electrical conductivity, chemical
activity, specific heat. The larger the water associates and the longer it is stored (aging), the less active it is [20]. Mono-molecules move faster than associates (Brownian motion), which contributes to the liquid mixing and accelerating chemical reactions. It can be assumed that the activation of water means the sum of phenomena, effects or new properties of the substance that occurs due to the use of techniques for controlling the reactivity of water without changing its elemental chemical composition. Any substance can be called activated. In this activated substance, the supply of internal energy is non-equilibrium for given values of temperature and pressure as a result of external action. In other words, activation is a long-term non-equilibrium state. During the activation process, water acquires excess potential energy.

3. Results
The analysis of the problem has shown [21] that a modern technology of thermal equipment cleaning with reagent-free method makes it possible to implement the following fundamental principles:

1. Descaling and deposit removal should occur without causing any damage to the surface being cleaned.
2. Simultaneously with cleaning process the contact of water with anti-corrosion protection on surfaces should be formed.
3. Preventing the formation of new scale in the subsequent operation of thermal equipment.
4. Ensuring the staff safety and conforming to the existing environmental and sanitary regulations.

Currently, many methods of thermodynamic water activation have been developed and successfully implemented combining efficiency, affordability and low cost.

As is known, water can be activated through its interaction with minerals. The thing is that they have energy and information fields that can affect the water, modifying it into a non-equilibrium thermodynamic state with increased internal potential energy. This is typical of only those minerals that are able to change the amount of H+ or OH- ions in water, or interact directly with water molecules, at least slightly dissolving in it.

The processing technology of heat supply and hot water supply systems by introducing powder from natural components (for example, medium-magnesium waste with a content of 15 - 45 % MgO, formed during the extraction, enrichment and processing of diopsides, serpentinites) previously passed physical and mechanical activation into circulating water or into the water supply reservoir of recirculated water supply or heat supply is of practical interest [21, 22]. Placed in water, it forms a slightly alkaline medium and gradually destroys intermolecular structural bonds in scale, converting the latter into sludge and partially dissolved. All the sludge formed during the operation of the boiler is removed by conventional technological purge. During the interaction of the minerals surface with water, hydration forces act at the interface "solid – water", their nature is associated with the quantum-mechanical interaction of nuclei and electron shells of atoms, ions, molecules. As a result of the hydration forces action (nuclear and electronic ones) on the surface of a solid, for example, a mineral, a very thin film of water consisting of several layers of H2O molecules is formed. The resulting energy field affects the scale actively, causing the weakening of the adhesion forces between the molecules in their thickness. As a result, the most durable deposits of scale are converted into a loose mass, gradually washed away by the flow of water.

The application of thermodynamic water activation method in combination with non-destructive methods of technical condition control will allow to replace the maintenance of thermal equipment according to the maintenance schedule (preventive maintenance) with transition to new maintenance modern systems of thermal equipment – condition-monitored maintenance systems, and to use proactive systems with the maximum possible overhaul life of the equipment through the use of modern technologies of detection and suppression of failure sources in the future.

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