

Review

Removing Scale Deposits from Heating Systems

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Abstract

Facilities in power plants and thermal power plants must operate at high efficiency. Their efficiency largely depends on the quality of water as a cooling medium. Water is the most commonly used cooling medium in processes because it is generally available and has a large thermal capacity. The use of water results in a variety of consequences. The different compositions of water can cause scale deposits and contribute to the corrosion of system components. The exacerbation of the problem depends on the composition of the water and the operating conditions of the system.

The lack of a low-cost and quick way to remove accumulated deposits that is also safe due to the chemicals used means that cleaning the system of deposits is not widely undertaken, especially in cases of small thermal power plants. Therefore, chemical cleaning is an extremely important part of plant operation. Due to the often-individual characteristics of each installation and the different sources of water as a refrigerant, it is important to know the different methods of descaling an installation. This article provides an overview of methods for descaling installations. Each of them has its own specific properties, allowing an individual approach to boiler scale removal.

Keywords: scale deposits, scale removing, heating systems, corrosion, chemical cleaning

Introduction

The need to use only sustainable raw materials and environmentally friendly energy production technologies makes it necessary to look for other ways to reduce pressure on the environment. One method is to reduce the demand for primary energy by increasing the efficiency of the equipment that makes up the energy infrastructure. One of the ways to achieve more

favourable operating indicators of thermal equipment and installations in the power and other industries is to improve the technological regime in heat exchange processes by eliminating the build-up of scale deposits in such equipment.

The equipment installed in power plants and combined heat and power plants must operate efficiently and with high efficiency. They depend heavily on water quality. Minimal exceedances of the normally permissible indicators can cause the formation of deposits on the walls of pipes and other equipment that impede heat transfer and promote the development of pipe corrosion. Protection against the corrosion

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of refrigeration systems poses great difficulties because of their complex geometry, large volume, and the presence of various metals. This makes it all the more necessary to treat the water that feeds such systems, which, due to changing factors such as salt and oxygen content, flow rate, temperature, and volume of water to be treated, is also not easy. The presence of algae and bacterial slime in the water must also be taken into account.

A problem that arises during the operation of industrial heating systems is the presence of phenomena that lead to adverse changes in the operation of equipment. The undesirable effect is the corrosive destruction of structural elements of the system, "microbial overgrowth" and, in particular, the precipitation of scale deposits. In refrigeration and heating systems, one of the main operational problems is the overgrowing of heat transfer surfaces with scale deposits precipitated from circulating water.

Water is commonly used as a refrigerant in many processes due to its general availability and high thermal capacity. However, using water is not without its drawbacks. The electrolytes contained in water can cause scale formation and corrosion of system components. There are 4 types of boiler scale [1]:

- White-beige carbonate scale, which, from a chemical point of view, is mainly a mixture of calcium and magnesium carbonates, but which may also contain magnesium hydroxide and iron oxides.
- Brown carbonate stone, which owes its colour to its high content of divalent iron.
- Grey sulphate stone, which is mainly composed of calcium salts. Over time, this transforms into glassy gypsum (hydrated CaSO_4) which is extremely difficult to remove.
- Brick-brown silica stone. This consists of silicates of Ca, Mg and Al.

The chemical composition of boiler scale varies depending on the origin of the boiler water (seawater, brackish water, river water, lake water, city water). According to its chemical composition, boiler scale can take the form of a constantly thickening, hard, tightly adhering stone or slime sinking to the bottom of the pipes. The internal pipes of central heating systems produce black scale with a high content of iron (III) oxide [2]. The presence of iron can result from the use of iron-rich water, but can also be the result of corrosion of the internal parts of the system. Steel tends to divide into anodic areas (where iron corrodes) and cathodic areas (where the oxygen reduction reaction takes place). In most places, the metal is exposed to flowing water (and the oxygen in it) and behaves cathodically. The anodes are small compared to the cathodes, but the electron current produced by the anodic areas must balance the electron current supplied to the cathodic area. As a result, steel corrodes quickly in a small area [3]. The severity of the problem depends on the composition of the water and the operating conditions. If the plant operates with open-circuit water, the amount of salt is

constantly replenished, which promotes the problem of growth. Another problem is equipment corrosion

In district heating systems, the places most prone to scale accumulation are heat exchangers and places where the flow is laminar. The thermal conductivity of stone is much lower than that of metal. Carbonate stone with a thickness of 1 mm causes an increase in heating temperature by 100°C , and silicate stone by up to 400°C [1]. Due to the accumulation of heat by the accumulated stone, distortion of pipes, bulges, and concave sections can occur, as well as cracks and damage to pumps, impellers and other components. As a result, the installation is at risk of failure and loss of safety.

Much research is targeted at the development of anti-scaling agents and corrosion inhibitors. In the light of growing environmental concerns, it is suggested that scale inhibitor and corrosion inhibitor additives should follow the principles of green chemistry [4, 5].

One of the solutions for removing calcium carbonates from water is decarbonisation with lime milk. The method is effective for water with high calcium hardness, non-carbonate hardness, and low magnesium hardness [6]. Dissolved calcium and magnesium salt particles in the water can be coagulated in an ultrasonic field and removed on a feedwater filter. Such a solution has been used in a marine steam boiler and has been found to be satisfactorily effective in preventing scale build-up [7]. Another method of water treatment that guarantees a high degree of demineralisation is the use of reverse osmosis [8]. A selective membrane is permeable only to solvent molecules. Water introduced to the reverse osmosis module must be pre-treated. Pre-treatment involves the removal of solids, water hardness, chlorine, iron, and manganese [9], so the additional treatment increases the cost of the process. Using a hybrid solution involving serial cooperation of ionite beds and reverse osmosis modules, high water quality requirements were achieved at the water treatment plant (SUW) for the Oncology Center in Bydgoszcz [8]. The combination of ultrafiltration and reverse osmosis also made it possible to treat the water of the Weser River in Germany [10] saving energy compared to conventional methods. The phenomenon of deposition of insoluble deposits and build-up in heating and industrial installations of the chemical, metallurgical and food industries is a well-known and very troublesome phenomenon. In some cases, after just a few months of operation, a layer of deposits of about 1mm thickness can form, which has a very negative effect on the efficiency of the equipment [11].

The scale deposited on the surface of thermal equipment and pipelines is a great insulator, which reduces the heat transfer capacity while increasing heat loss. The layer of sediment is responsible for the operational difficulties of the entire heating system and, above all, for higher electricity consumption for the operation of these devices and a decrease in the efficiency of the system. The scale has low thermal permeability, which causes local underheating (or

overheating), which can consequently cause system failure [12].

The purpose of the article is to present various methods of descaling. The authors focus on discussing the methods available at this moment, which are most commonly used to remove scale from the installation. The article focuses on a literature review and a discussion of the possibilities offered by the descaling methods.

Methodology

The literature review involved analysing articles according to keywords:

- descaling,
- descaling methods,
- methods of descaling in heating systems
- heating systems.

Based on the literature examined, an analysis was made of the links between documents, authors, co-citation, institutions or countries that publish the most on this subject. The analysis of the literature was performed in the VOSviewer program. It is a software tool for constructing and visualizing bibliometric networks. These networks may for instance include journals, researchers, or individual publications, and they can be constructed based on citation, bibliographic coupling, co-citation, or co-authorship relations. VOSviewer also offers text mining functionality that can be used to construct and visualize co-occurrence networks of important terms extracted from a body of scientific literature. Graphs were created showing the following links between publications:

1. Co-occurrence – Keywords
2. Co-citation – Cited sources
3. Co-authorship – Authors
4. Co-authorship – Countries
5. Bibliographic-coupling – Documents

6. Bibliographic-coupling – Countries

The literature analysis was based on articles from 2018-2022. The graphs below show the time frames in which the most articles on this topic were published.

Fig. 1 shows the connections between Co-occurrence – Keywords.

Co-occurring keywords that can be found in articles based on graph analysis are descaling, mechanisms, adsorption, mild-steel and copper. Graph analysis indicates articles written in 2019 and 2020. The word “mild-steel” is linked in the graph to the four words “descaling”, “adsorption”, “copper”, “mechanism”.

Fig. 2 shows the connections between Co-citation – Cited sources.

The literature analysis identified 7 journals for Co-citation links – Cited sources. Graph analysis shows that the largest number of articles on this topic have been published in the Journal Corrosion Science. The VOSviewer program shows that it is cited 153 times over the 2018-2022 period. Journals that publish on this topic and have cited the Corrosion Science journal include the Journal of Molecular Liquids (50 citations), Desalination Journal (61 citations), Electrochimica Acta (22 citations), Applied Surface Science (20 citations), Industrial & Engineering Chemistry Research (24 citations).

Fig. 3 shows the graph with connections between Co-authorship – Authors.

It can be seen that there are 7 authors on the graph and 6 links come out from each of them. In the middle of the graph, there is author Wu, who is related to each of the other authors. The largest number of articles were published in 2019 by Zhigang, Yang, Liqun, Shuo and Ri. Two authors were published in 2020.

Fig. 4 shows the connection between Co-authorship–Countries.

It can be noted that co-authorship with countries is the largest in China. Based on a graph analysis in VOSviewer, there are more than 20 co-authorships in this country. Other countries that publish many items

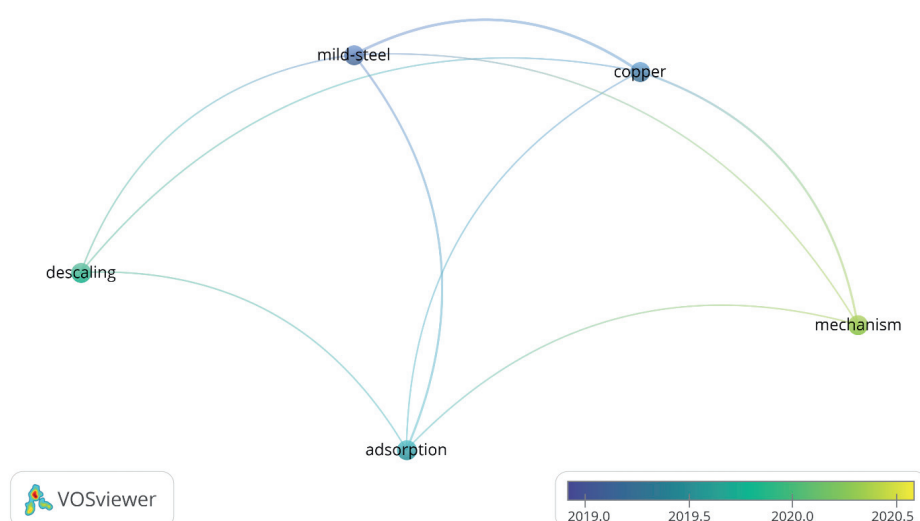


Fig. 1. Connection between Co-occurrence – Keywords.

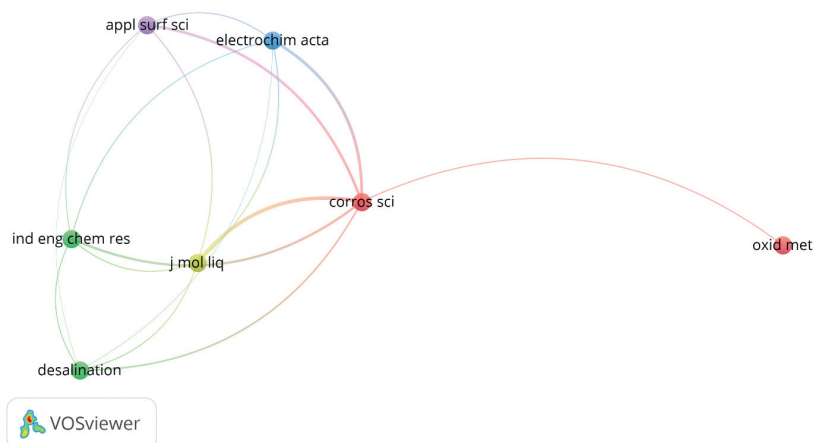


Fig. 2. Connections between Co-citation – Cited sources

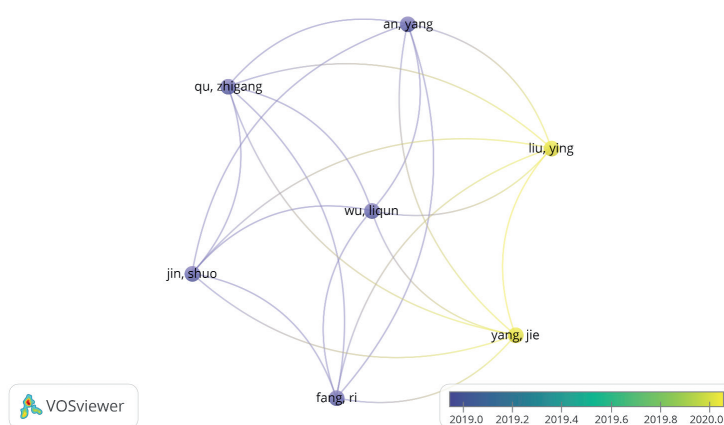


Fig. 3. Connections between Co-authorship – Authors

on this topic are Poland and Saudi Arabia. The timeline shows that Saudi Arabia began publishing the earliest of the countries indicated on the graph - 2019. China has had publications since 2020, while Poland began publishing in mid-2020.

Analysis of the graph indicates that the document authored by Goyal in 2018 is the starting document for most of the other items that were created in later years. His publications have been cited 215 times. The second highest citation rate is Obot with 50 publication citations. The vast majority of authors are publishing in 2020/2021.

Fig. 6 shows the connections between Bibliographic-coupling – Countries.

In the relationship between Bibliographic-coupling – Countries it can be seen that the most connections can be found for China, while the graph also lists South Korea, India and Poland. Based on the VOSviewer program, China has 21 documents cited by the other 4 countries shown in the graph. South Korea has 4 documents, while the rest of the countries have 3 documents each. Publications from China are from the early 2020s. Poland has the most recent publications according to VOSviewer.

Characteristics of Scale Deposits

The literature review involved analysing articles according to keywords:

- boiler scale deposits (Fig. 7),
- chemical composition of boiler scale deposits (Fig. 8),
- carbonate boiler scale (Fig. 9),
- sulphate boiler scale (Fig. 10).

Figs 7-10 show graphs with connections between co-occurrence – keywords.

The graph shown in Fig. 7 shows the relationship between the keywords for the words “boiler scale deposits.” The program is divided it into 5 subject areas - clusters. This is the most complex graph of all those that were made during the literature analysis. The keywords that have the most associations are “combustion”, “boiler”, “corrosion”, “hot corrosion”.

The keywords in Fig. 8 for “chemical composition of boiler scale deposits” are “corrosion”, “biomass”, and “combustion”. All three are linked with each other.

Fig. 9 shows the relationships for “carbonate boiler scale.” Two groups - clusters - are visible here. Words

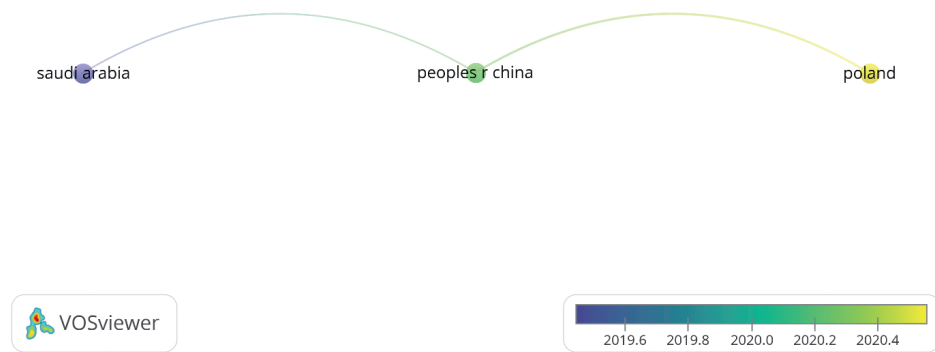


Fig. 4. Connections between Co-authorship-Countries

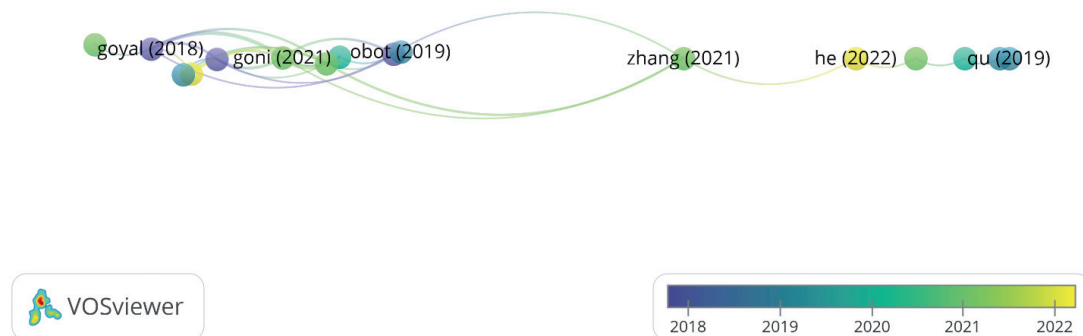


Fig. 5. Connections between Bibliographic-coupling – Documents

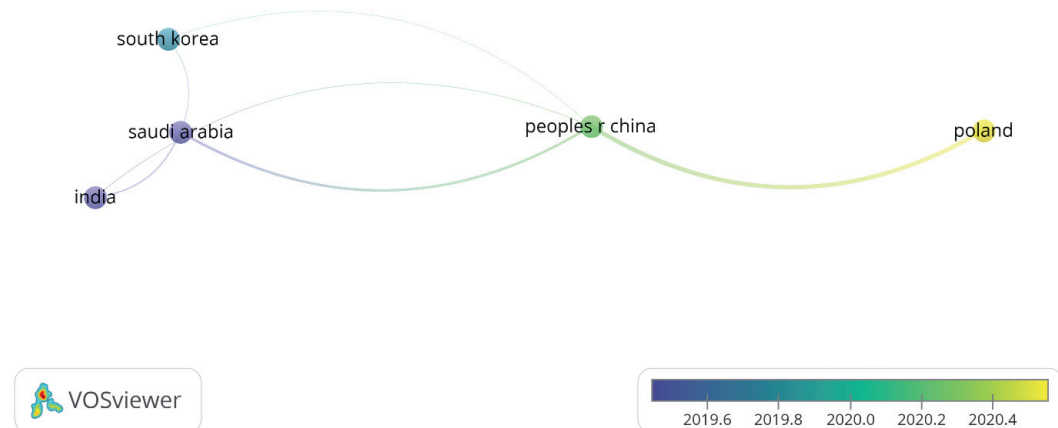


Fig. 6. Connection between Bibliographic-coupling – Countries

such as “corrosion”, “desalination”, “waste-water” and “magnesium”, “calcium”, and “hardness removal” can be distinguished here.

Fig. 10 shows the relationships for “sulphate boiler scale.” There are 4 words that are highlighted here: “coal”, “biomass”, “corrosion”, “combustion”. Each of these words is related to the others.

Scale deposits occurring in thermal equipment can be divided into mechanical, hydrobiological and chemical [19].

Mechanical deposits are impurities of various origins, most often sand, silt and clay. They arrive with

the water. There is often a large quantity of mineral suspended solids in the water which must be removed by filtration. If scale forms on the metal surface in the system, then mechanical impurities settle together with the scale. Fast flow reduces the amount of mechanical impurities deposited [20].

Hydrobiological deposits form in such systems in locations where there are favourable conditions for the growth of microorganisms. The most important microorganisms include ferrous and sulphur bacteria, as well as fungi and algae. Sulphur bacteria produce H_2S and cause pitting corrosion. Ferruginous bacteria do not

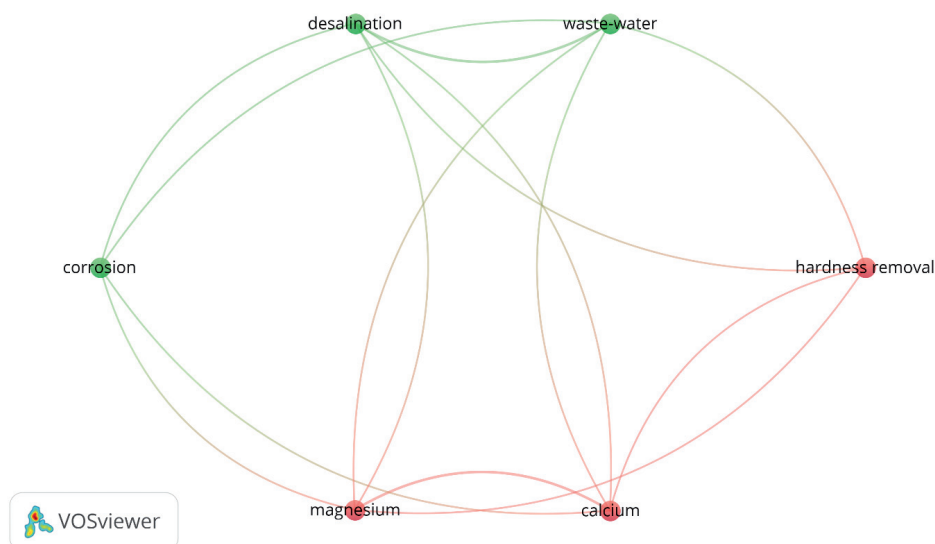


Fig. 9. Connections between co-occurrence and keywords in the articles related to the topic - carbonate boiler scale.

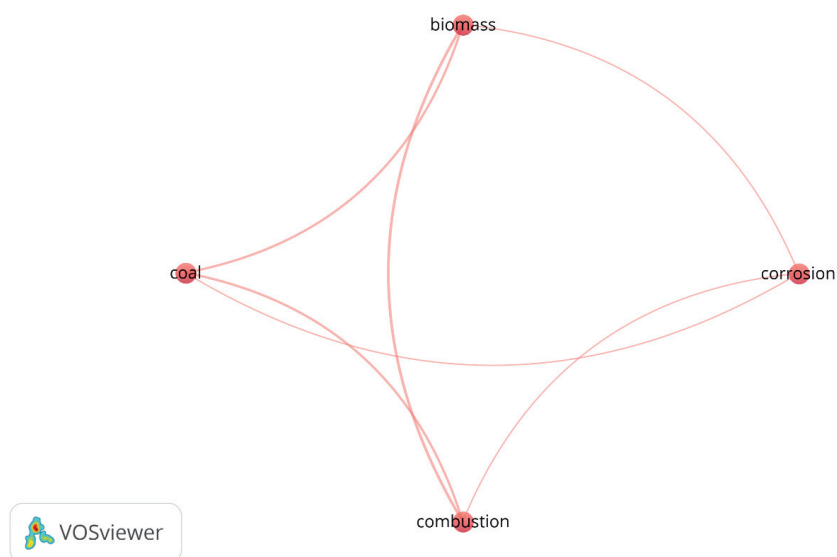


Fig. 10. Connections between co-occurrence and keywords in the articles related to the topic -sulphate boiler scale.

Typical feedwater contaminants that can form deposits in boilers include calcium, magnesium, iron, aluminium and silica. Deposition is mainly due to the presence of calcium and magnesium salts (carbonates or sulphates), which are less soluble when hot than when cold, or because the silica concentration is too high relative to the alkalinity of the boiler water. These salts reach the deposition site in soluble form and precipitate out.

The deposition of crystalline deposits on the boiler walls interferes with heat transfer and can cause “hot” spots, leading to localised overheating. The less heat the deposits conduct, the more dangerous they are. Their thermal conductivity values are [$\text{kcal/m}^2 \text{ h } ^\circ\text{C}^{-1}$]: steel - 15; CaSO_4 1-2; CaCO_3 0.5-1; SiO_2 0.2-0.5 [22]. There are four basic types of scale deposit:

- Carbonate scale - occurs when the water softening system is not working properly, when calcium and magnesium ions enter the boiler in addition to carbonates. Such scale is white or beige and can contain up to 50% calcium carbonate, with the addition of magnesium carbonate and magnesium hydroxide, as well as iron oxides, which are products of corrosion.
- Carbonate scale with divalent iron precipitate - in installations constructed of iron, a brown carbonate scale is formed, which is overgrown with divalent iron precipitate and corrosion products.
- Sulphate scale - is grey in colour and is mainly composed of calcium sulphate. It is hard, tighter, and more difficult to remove than carbonate scale. It is difficult to dissolve and has three times lower

thermal conductivity. If not removed, it hardens further as a result of increasingly high temperatures, over time turning into white gypsum.

- Siliceous stone - is most often brick-red or maroon in colour and is formed on the most heat-stressed parts of the nodes. It consists of calcium and magnesium silicates and aluminosilicates. It has high hardness and low thermal conductivity [16].

Carbonate deposit is usually granular and sometimes very porous. The calcium carbonate crystals are large, but are usually mixed together with finely divided particles of other materials, making the deposit appear dense and uniform. Testing the precipitate in an acid solution can easily identify a carbonate bed [8].

A sulphate deposit is much harder and denser than a carbonate deposit because the crystals are smaller and cement more firmly. Sulphate sludge is brittle, but does not grind easily or “effervesce” when added to acid.

Sludges with high silica content are very hard and resemble porcelain. The silica crystals are extremely small, forming a very dense and impermeable rocky deposit. This rock is extremely hard and very difficult to pulverise. It does not dissolve in hydrochloric acid and is usually very light in colour [12].

Iron deposits, formed by corrosion or deposition of iron impurities from water, are very dark in colour. Boiler deposits of iron are usually magnetic. They dissolve in hot acids, forming a dark brown solution. In addition to methods of removal, there are methods to prevent the formation of deposits, for example, by adding suitable inhibitors or preparing the surface of the heat exchanger [23]. For example, spreading gum arabic on the heat exchanger surface reduces the number of deposits [24].

Selection of Chemical Cleaning Technologies

The selection of a chemical cleaning technology for new equipment is relatively straightforward, as it is known in advance what type of contaminant needs to be removed [25]. However with equipment which is already in operation, the composition, structure, and thickness of the deposits can vary and depend on the operating conditions [26]. Contaminants can even be found which vary significantly from one place to another in the same equipment [27]. Hence, the selection of the right reactants and cleaning technology is complicated and always requires testing [25].

A chemical cleaning method has been developed in which material deposited inside thermal equipment is dissolved with the help of an innovative biodegradable preparation in which, in addition to the main decalcification component, there are corrosion inhibiting, antifoaming and antimicrobial components [26]. The growth of microorganisms on moist surfaces results in biofilm formation [27]. The effect of the uncontrolled growth of microorganisms on the surfaces of structural elements is the deposition of slime [26].

The descaling compound developed has decalcification, anti-corrosion and anti-microbial properties [27]. The enrichment of the compound with anti-microbiological properties was achieved by introducing zinc ions into its formula [28]. The base component of the product exhibits anticorrosive properties, which, combined with its anti-microbiological properties, makes it suitable for use in circulating water systems. The use of copper and zinc as preservatives in the circulating liquid will introduce simultaneous continuously active biocidal activity against bacteria and algae [29]. In this way, the product will also reduce the physiological activity of microorganisms, thereby eliminating the growth of problematic biomass [27].

Engineered water, for economic reasons, is often used in systems that operate in closed or periodically replaced systems [30]. Installation systems are successively exposed to bio-pollution due to the supply of untreated tap water and contamination from production, the materials used or the operating personnel [31]. As a consequence of the long-term use of water systems in the presence of available nutrients in the water, there is a gradual proliferation of microorganisms and formation of biofilm, about 95% of which is observed on surfaces, while about 5% is observed in the circulating water [32].

Potential customers for chemical descaling technology are companies where the cleaning of district heating equipment and cooling systems is required for heat exchangers and hot water storage tanks, open-cycle central heating boilers, central heating boilers with cast iron inserts, hot water storage tanks, central heating installations, steam generators, steam boilers, heat transfer pipelines, spray-extraction condensers, cooling towers, tube condensers, ammonia-exchange condensers, refrigeration units, circulating pumps and fittings, compressor coolers and chillers [33].

The application of the technology can contribute to gaining a market advantage over competitors offering products based on traditional components [34]. The proposed method can be particularly useful for cleaning central heating systems including superheated water circuits, cold water circuits, solar installations, heat pumps, and closed primary and secondary heating circuits in construction and industry [35].

Corrosion Protection of Heating Systems

The literature review involved analysing articles according to keywords:

- corrosion protection of heating systems (Fig. 11),
- phosphoric acid as a cleaning agent for boiler scale,
- hydrochloric acid as a cleaning agent for boiler scale,
- EDTA as a cleaning agent for boiler scale.

Due to the limitations of the program, the literature on the issue of corrosion protection of heating systems

is presented in the literature review in VOSviewer (Fig. 11).

The keywords in Fig. 11 represent the topic “corrosion protection of heating systems.” The program created a graph with 29 keywords in five groups - clusters.

The corrosion protection of heating systems involves great difficulties due to their complex geometry, high efficiency and the presence of various metals. It is necessary to treat water for use in such systems, which is not easy due to changing factors or components such as the salt and oxygen content, flow rate, temperature and volume of treated water. In addition, the presence of algae and bacterial slime in the water must be taken into account [36].

Sediment build-up reduces the efficiency of equipment operation, as well as transmission capacity, resulting in an increase in the energy required to pump water. The primary factors associated with build-up can be [24-26]:

- velocity; the higher the velocity, the lower the chance of sediment formation,
- pH, liquid temperature, heat transfer surface temperature,
- surface material; the higher the heat transfer coefficient of the material, the greater the susceptibility to build-up (copper> aluminium> brass> stainless steel) [27],
- surface roughness to increase deposition [27],
- type of heat exchanger.

The problem of scale build-up forces the selection of appropriately sized heat exchangers at the design stage, as the decrease in heat transfer efficiency over time must be taken into account. The purchase and installation of larger equipment incurs costs at the investment stage but does not relieve additional costs at the use stage.

Oversized equipment also increases heat loss to the environment as well as thermal inertia [28].

Scale removal methods include chemical, biological and physical methods that vary in the degree of effectiveness of boiler scale removal. Alternative methods also include magnetic, electronic and electrolytic methods [29]. In addition, the paper also mentions a method of leaching settled compounds in flow channels using clean water at the appropriate high stream pressure, which can be applied to fresh deposits (work on the so-called fresh bed) [37]. The use of these methods requires the proper design of exchangers. The hydrodynamic cleaning method is also used for sanitary purposes. The high-pressure jet increases the effects while reducing the time [38].

The current lack of low-cost and fast methods of removing sludge which are nevertheless safe due to the chemicals used means that the cleaning of sludge from plants is not widely used, especially for small thermal plants. Nevertheless, chemical cleaning is an extremely important element in the protection of thermal equipment [39]. If carried out correctly with appropriate technological regimes, the chemical cleaning process can minimise the risks associated with the cleaning process [40].

The characteristics of the sludge bed are influenced by the properties of the raw water, the type of external treatment, the methods and control of feed water treatment, as well as the nature and degree of external contaminants that have entered the feed water during exchanger operation [41].

Environmental regulations must be taken into account when choosing a solvent [42]. Plants without waste treatment facilities must export used cleaning agents or must use a process in which the solution used can be evaporated. The choice of solvent should be

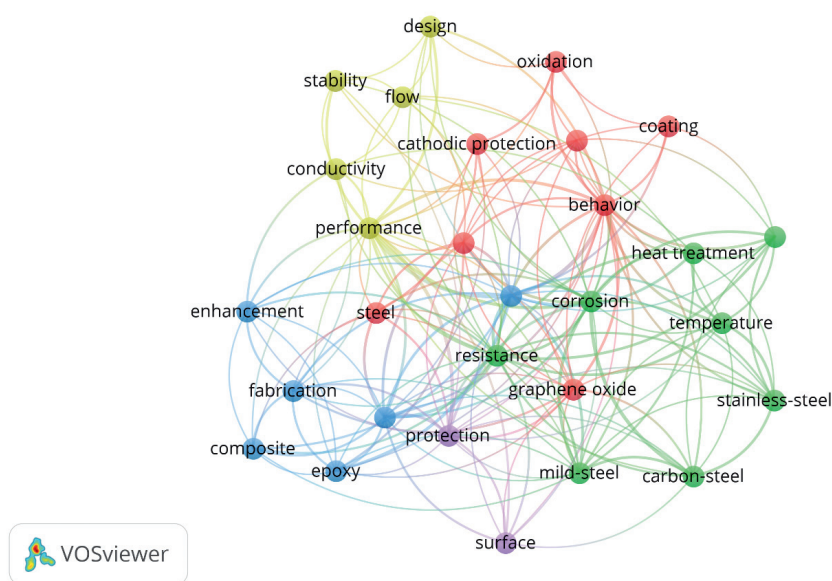


Fig. 11. Connections between the co-occurrence and keywords in the articles related to the topic - corrosion protection of heating systems.

based on laboratory testing of a sample of the sludge in the exchanger tube [43]. This will help ensure that the expected chemical cleaning results are achieved with minimal cost and risk to equipment and the environment. Inhibited hydrochloric acid is the most commonly used sludge solvent [44] since it effectively removes most calcium and iron deposits. Hydrofluoric acid or ammonium fluoride is often added to hydrochloric acid to help remove sediments containing silicates [45]. This mixture is also used to accelerate the removal of some complex sludges.

Chelating agents, such as EDTA and citric acid, are used to dissolve iron oxide deposits [46]. They can also be used to dissolve copper oxide deposits by injecting an oxidising agent into the boiler water circuit [31].

Proper chemical cleaning removes deposits from inside the boiler tubes, which improves the boiler heating rate, reduces tube failure and improves the chemical stability of the boiler [47]. However, chemical cleaning is expensive. The need for chemical cleaning of a boiler should be determined by the number of deposits in the exchanger tubes, not by the time elapsed since the last cleaning [48]. Improvements in boiler operation and feedwater chemistry, as well as the rules of operation, can extend the time between cleaning operations. Together, these techniques and practices can also save money and help reduce the risk of forced shutdowns [33, 30].

The use of chemical agents is the most common method of descaling. These agents are usually based on the action of inorganic acids, i.e., H_3PO_4 , HF, HCl, and HNO_3 , less often on that of organic acids, e.g. citric acid, or bases. The effect of different acids on the removal of sludge from the heat exchanger was studied in one paper [34]. Different acid concentrations indicate that the more concentrated the acid, the greater the scale removal rate. The effect of corrosion inhibition at different acid concentrations, with the addition of hexamine and glutamine, was studied using a weight-based method. The results indicate that the inhibition efficiency increases with increasing concentration of inhibitors [35], and the longer the dissolution time, the higher will be the efficiency. Theoretical calculations show that using a 2.5 M HCl solution with 0.80 grams of glutamine for 2.5 hours gives the best descaling results.

Inhibited 5-20% hydrochloric acid is very effective in removing scale and iron oxide [35]. It can be used to remove deposits consisting mainly of carbonates with smaller amounts of phosphates, sulphates and silicates. This type of deposit usually occurs in a steam boiler system containing copper alloys that have been treated with phosphate-based solvents. Depending on the specific application of the descaler, some of its components may be omitted from the formulation. For example, diethyl thiourea is not needed if there is no copper in the system. It should be noted that if diethyl thiourea is used, the waste should be treated as hazardous waste. If only carbonate sludge is to

be removed, ammonium difluoride, which is used to remove silica sludge, can be omitted [49].

According to [36], the cleaning agent for descaling the internal surfaces of heat exchangers are 75% phosphoric acid solution, 31% hydrochloric acid solution, EDTA, glycol, glycerol and water. The selected individual components in the formula also provide protection of the surface from damage during the descaling process. The operating temperatures and pressures used during cleaning as recommended are 45-65°C and 2 to 6 bar, respectively. In order to increase the effectiveness of active agents, the flow rate of the formulation should be 25-50 dm³/min. The authors assume the possibility of repeated use of the mixture, which remains active up to pH = 3.5. This composition requires a high concentration of strong acid (hydrochloric acid). It does not contain any corrosion inhibitors that would significantly reduce damage to cleaned surfaces or antimicrobial substances that remove biofilms. The disadvantage of using the solution is the requirement of high temperature, which significantly increases the energy consumption of the cleaning process.

The Demclean 94® cleaning method [38] is based on EDTA. In a neutral pH environment it removes not only iron oxides, but also light oil, grease and atmospheric contaminants. Rust (iron oxides) dissolves to form a strong iron-EDTA complex. This allows the pH to increase following cleaning without iron precipitating as ferric hydroxide. After neutralisation, the steel is rendered passive by dosing with sodium nitrite. The wastewater released by this cleaning procedure can be treated by biological water treatment modified to process EDTA. Advantages: pH-neutral cleaner; rendered passive with a cleaning solution; less wastewater; no corrosion of other metals; time saving. Disadvantages: addition of chemicals during the rendering-passive phase; limited iron solubilisation capacity. Wastewater can only be treated biologically.

One of the decalcification products proposed is DoroFos, consisting [40] of the above-mentioned concentrate and water in a ratio of 1:7 to 1:11, preferably 1:9 (v/v). This is an innovative, biodegradable formulation in which, in addition to the main decalcifying ingredient (phosphoric acid solution), there are corrosion inhibitors, anti-foaming substances and antimicrobial substances. The enrichment of the composition with antimicrobial properties was achieved by introducing copper and zinc ions into the composition. The composition has anti-corrosive properties [9], which, combined with its anti-microbial properties, makes it suitable to use in circulating water systems. The use of copper and zinc as preservatives in the circulating liquid has made it possible to achieve simultaneous, continuously active biocidal activity against bacteria and algae. In this way, the product also reduces the physiological activity of microorganisms and thus eliminates the growth of problematic biomass [39].

The cleaning method analysed involves a chemical process which dissolves scale accumulated inside

heating equipment using a concentrate containing phosphoric acid (V) at a concentration of 75 to 85% H_3PO_4 and inhibitors selected from a group consisting of formalin, ammonium chloride, copper sulphate, and zinc sulphate. The chemical composition of the formulation was selected on the basis of laboratory tests. The main ingredient is phosphoric acid, which at a concentration of 8-10% H_3PO_4 best dissolves scale deposits. The addition of sodium pyrophosphate increases the dissolution rate and facilitates the formation of complex compounds of insoluble or hardly soluble salts in phosphoric acid. Zinc oxide, on the other hand, intensifies the dissolution of iron compounds contained in scale and accelerates the removal of rust from the metal surface. A 1:1 mixture of formalin and ammonium chloride is used as a corrosion inhibitor. The addition of formalin simultaneously prevents the formation of foam during the dissolution of carbonate deposits [39, 41].

Paper [43] studied the effect of different acids on the removal of scale from a heat exchanger. Different concentrations of acids were tested, and it was found that higher concentrations resulted in increased sediment removal. Different concentrations of hexamine and glutamine were used as inhibitors. Inhibiting efficiency increases with increasing inhibitor concentrations, and scale dissolution time is an important factor in the effectiveness of acid and inhibitor use. It was also found that the higher the temperature of the acid, the higher the rate of scale dissolution.

Patent [44] presents an agent for removing corrosion while providing simultaneous protection against corrosion, especially of open and closed hydraulic systems based on hydrochloric acid and citric acid, containing urotropine, and supplemented with water. It contains hydrochloric acid at 1 to 5 parts by weight, formic acid at 1 to 5 parts by weight, citric acid at 1 to 10 parts by weight, tannin at 1 to 5 parts by weight, ethanol and butanol-1 2 to 10 parts by weight, urotropine 1 to 5 parts by weight, tolyl-triazole at 0.5 to 2 parts by weight, zinc sulphate at 1 to 3 parts by weight and water at 55 to 90.5 parts by weight.

Methods of corrosion testing and the methods used to evaluate such tests, the principles of corrosion protection, and corrosion inhibitors are presented in [50]. This paper also gives many examples of corrosion-resistant materials, that is, materials that can be used in aggressive environments without additional protective treatments.

Summary

Systems installed in power plants and combined heat and power plants must operate efficiently and with high efficiency. Their operating efficiency largely depends on the quality of water as a cooling medium. Water is a commonly used cooling medium in many processes due to its general availability and high heat capacity. However, the use of water is not without disadvantages.

Electrolytes in water can cause scale formation and corrosion of system components. Minimal levels exceeding permissible ratios can cause deposits on the walls of pipes and other equipment that impede heat transfer and promote the development of pipe corrosion. Protection against corrosion of refrigeration systems poses great difficulties due to their complex geometry, large volume, and the presence of various metals. This makes it all the more necessary to treat the feed water of such systems, which, due to changing factors such as salt and oxygen content, flow rate, temperature, and volume of water to be treated, is also not easy.

The chemical composition of scale varies depending on the origin of the boiler water. Internal pipes of central heating systems produce black scale which has a high content of iron (III) oxide. The presence of iron may be due to the use of iron-rich water, but can also be the result of corrosion of internal system components. The severity of the problem depends on the composition of the water and the operating conditions. If the plant is operating with open-circuit water, the salts are constantly being replenished, which promotes an increase in the problem. Another problem is the corrosion of equipment. As a result of heat accumulation by accumulated scale, pipe deformation, bulges, and concave sections can occur, as well as cracks, and damage to pumps, impellers and other components. Consequently, the installation is at risk of failure and loss of safety. In light of growing environmental concerns, it is suggested that additives for scale inhibitors and corrosion inhibitors follow the concept of green chemistry.

To date, the lack of a low-cost and quick way to remove accumulated deposits, means that cleaning the plant of deposits is not widely undertaken. Therefore, chemical cleaning is an extremely important part of plant operation. Proper execution of the chemical cleaning process, will minimise the risks arising from the above-mentioned factors. Due to the often-individual characteristics of each installation as well as the different sources of water as a refrigerant, it is important to know the range of methods available for descaling the installation. Each of the methods discussed in this article has specific properties. This allows an individual approach to the descaling process.

Conflict of Interest

The authors declare no conflict of interest.

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