Nafta-Gaz 2024, no. 2, pp. 115–121, DOI: 10.18668/NG.2024.02.07

Investigations of the impact of the magnetic field on the process of formation of scaling in thermal devices

Badania wpływu pola magnetycznego na proces tworzenia kamienia w urządzeniach termicznych

Oybek Ismailov[1], Abdugaffor Khurmamatov[1], Mirzaakbar Ismoilov[1], Alisher Auesbaev[1], Usnatdin Utegenov[2]

[1] *Institute of General and Inorganic Chemistry of the Academy of Sciences of the Republic of Uzbekistan*
[2] *Karakalpak State University named after Berdakh*

ABSTRACT: Water is used as working fluids in hydro and thermal power engineering, as well as in heat supply and cooling systems. In the process of heating water in water-heating boilers, scale forms due to the precipitation of crystals of mineral additives and mineral salts. Over time, the accumulation of scale with low thermal conductivity leads to a decrease in the internal diameter of the pipes. Consequently, the flow of liquid is hindered, the hydraulic resistance increases and the thermal conductivity of the device decreases. The scale layer is usually removed by acid washing of the internal heat exchange surfaces or mechanical washing. However, both methods involve the use of a substantial amount of chemicals and result in highly polluted wastewater. In addition, it significantly increases operating costs. The article uses statistical methods for processing experimental data, and generally accepted methods for conducting experiments to study the patterns of scale formation using control and measuring instruments and accurate methods for measuring technological parameters. The main purpose of the paper is to study the influence of a constant magnetic field on the formation of mineral salts deposits on the surface of walls of thermal appliances used in chemical, oil refining, and food processing industry. The influence of a constant magnetic field on the formation of scale on the surface of the walls of the heating element in a water heater has been established. According to the results of an experiment aimed at preventing the accumulation of mineral salt deposits on the surface of the heating element in a water heating boiler under the influence of a magnetic field, the amount of mineral salt precipitate deposited on such surface can be reduced up to 5.2 times. Consequently, the prevention of mineral scale formation is achieved, eliminating the need to use expensive chemicals. The stable operation of the devices contributes to enhanced thermal efficiency. Under the influence of a magnetic field, scale formation decreases on average by a factor of 5, as long as the water temperature does not exceed 70°C. However, if the temperature rises above 90°C, the scale formation rate gradually increases.

Key words: heating devices, permanent magnet, sediment, water heating boiler, mineral scale, thermal efficiency.

STRESZCZENIE: Woda jest wykorzystywana jako płyn roboczy w energetyce wodnej i cieplnej, w systemach ciepłowniczych i chłodniczych. W procesie podgrzewania wody w kotłach wodnych powstaje kamień kotłowy w wyniku wytrącania się kryształów dodatków mineralnych i soli mineralnych. Z biegiem czasu wzrost grubości kamienia o niskiej przewodności cieplnej prowadzi do zmniejszenia wewnętrznej średnicy rury. W rezultacie przepływ cieczy staje się utrudniony, wzrasta opór hydrauliczny i maleje przewodność cieplna urządzenia. W celu usunięcia warstwy kamienia stosuje się zwykle mycie kwasem wewnętrznych powierzchni wymiany ciepła lub oczyszczanie mechaniczne. Wszystkie te metody wiążą się z użyciem dużej ilości chemikaliów i wytwarzaniem mocno zanieczyszczonych ścieków. Ponadto znacznie zwiększają one koszty eksploatacji. W artykule zastosowano metody statystyczne przetwarzania danych eksperymentalnych oraz ogólnie przyjęte metody prowadzenia eksperymentów do badania przebiegu powstawania kamienia kotłowego za pomocą przyrządów kontrolno-pomiarowych oraz dokładne metody pomiaru parametrów technologicznych. Głównym celem pracy jest zbadanie wpływu stałego pola magnetycznego na powstawanie osadów soli mineralnych na powierzchni ścianek urządzeń cieplnych stosowanych w zakładach przemysłu chemicznego, rafineryjnego i spożywczego. Określono wpływ stałego pola magnetycznego na powstawanie kamienia kotłowego na powierzchni ścianek elementu grzejnego podgrzewacza wody. Zgodnie z wynikami eksperymentu mającego na celu zapobieganie osadzaniu się osadów soli mineralnych na powierzchni elementu grzejnego w kotle wodnym pod wpływem pola magnetycznego, ilość osadów soli mineralnych osadzonych na powierzchni elementu grzejnego kotła wodnego można zmniejszyć nawet 5,2-krotnie. W rezultacie zapobiega się tworzeniu kamienia kotłowego i nie stosuje się drogich chemikaliów.

Corresponding author: A. Auesbaev, e-mail: *alisherauesbaev@gmail.com*

Article contributed to the Editor: 03.08.2023. Approved for publication: 27.12.2023.

Sprawność cieplna urządzeń osiągana jest dzięki możliwości stabilnej pracy urządzenia. Tworzenie się kamienia pod wpływem pola magnetycznego zmniejsza się średnio 5-krotnie, dopóki temperatura wody nie przekroczy 70°C. Jednakże, gdy temperatura wzrośnie powyżej 90°C, tempo tworzenia się kamienia stopniowo wzrasta.

Słowa kluczowe: urządzenia grzewcze, magnes trwały, osad, kocioł wodny, osad mineralny, sprawność cieplna.

Introduction

The scale is composed of calcium carbonate, magnesium hydroxide, and calcium sulfate. Among these, calcium carbonate is predominant and exists in the form of calcite crystals. The deposition of calcium carbonate leads to scaling in pipes, causing issues in industrial and commercial water distribution systems. Scale formation occurs due to the precipitation of sparingly soluble salts like calcium carbonate ($CaCO_3$) forming encrustations on the walls of water supply pipes. High temperature and pressure in water systems (e.g. boilers, heat exchangers, or hot water pipes) reduce the solubility of $CaCO_3$, leading to gradual formation of scale deposits that reduce the water-carrying capacity of pipes (Glater et al., 2012; Zendehboudi et al., 2014; Khormali et al., 2018). The oil industry and academia have investigated new technologies and tools to prevent and control scale formation in reservoirs, production columns, and process equipment. In petroleum fields, scales contain mainly barium sulfate, $BaSO_4$, strontium sulfate, $SrSO_4$, calcium sulfate, $CaSO_4$, iron carbonate, $FeCO_3$, and calcium carbonate, $CaCO_3$ (Reis et al., 2011; Vazirian et al., 2016).

In the oil refining and chemical plant industries, precipitation is observed in thermal installations. These precipitates form due to the crystallization of minerals and mineral salts present the raw material. Sludge formation in thermal installations extends over a certain period of time, and mineral scale formation on the surface of the device is accelerated due to low flow rates in pipes and prolonged exposure of the raw material to high temperatures. The gradual increase in the thickness of the deposit with lower thermal conductivity over time leads to a reduction in the inner tube diameter of the device (Kolesnikov and Nechayev, 1980). This leads to hindered fluid passage, increase in the hydraulic resistance of the pipe accompanied by simultaneous decrease in the thermal efficiency of the device due to a decline in the heat transfer coefficient (Ismailov et al., 2017). Addressing these issues necessitates the development of new technologies, hardware equipment, or the modernization of existing installations and production facilities, contributing to enhanced product competitiveness and a reduced energy costs for processes (Khurmamatov and Auesbaev, 2023).

It has been established that heat losses in heat exchangers range from 2 to 8%, whereas during the scale formation process, this figure can reach up to 60% (Ismailov and Ramonov, 2017). Proper selection of the process flow regime is crucial for the normal operation of thermal devices. Higher flow parameters prevent the formation of mineral scale deposits on the inner surface of the pipes, while high concentration of minerals in the raw material and high temperature promote it (Fedotkin and Lipsman, 1972).

Substances dissolved in water can lead to various malfunctions in the operation of power plants, primarily due to the formation of deposits and corrosion in thermal units. In addition to carbonate deposits in heating boilers, when water is heated above 130°C, the solubility of $CaSO_4$ is significantly reduced, which requires the adoption of standard wastewater quality to prevent gypsum precipitation from solution (Ochkov, 2006; Kostyleva et al., 2018).

In heat exchange equipment operating at temperatures between 25°C and 50°C, low-temperature deposits, primarily composed of calcium carbonate ($CaCO_3$), are often formed. The resulting sediment significantly reduces the heat capacity of heat exchangers (sometimes requiring additional installation), and also contribute to increased pressure loss in the pipes. When preparing hot water using deaerated water in hot water boilers (heating water up to 70°C), the formation of deposits of mineral alloys can be increased. Therefore, the use of such water without pretreatment is limited by relevant regulations (Shchelokov, 2002; Bannikov, 2004; Mosin and Ignatov, 2011).

Besides carbonate precipitates, deposits formed as a result of corrosion accumulate in thermal equipment. The composition of deposits from water heaters is quite typical (the composition is given as a percentage): Ca – 25.96; MgO – 1.97; Fe_2O_3 – 23.46; SiO_2 – 6.2; SO_2 – 0.42 (Prisyazhnyuk, 2004; Koshoridze and Levin, 2009; Ismoilov and Ismailov, 2022).

Conventionally, chemical treatment is employed for scale prevention. To mitigate adverse effects of chemical treatment, a non-chemical treatment is preferred as an alternative scale removal method. Magnetic water treatment (MWT) is a physical treatment that neither comes into direct contact with water nor undergoes chemical reactions with it. MWT has been used since the 1890s and was first patented in 1945 in Belgium (Vermeiren, 1958). Subsequently, there has been a global rise in the adoption of magnetic technology for water purification (Kobe et al., 2002).

Studies on the application of magnetic fields for scale prevention o have primarily focused on inhibiting the formation of $CaCO_3$ its subsequent incrustation (Cefalas et al., 2008;

Chang and Tai, 2010; Kozic et al., 2010; Sohaili et al., 2016; Al Helal et al., 2019). The suggested main effect is the acceleration of the nucleation process, leading to a greater number of the formed nuclei and, consequently, a reduction in the particle size of the precipitates (Chibowski and Szcześ, 2018). In addition, changes in the crystalline structure have also been observed (Chang and Tai, 2010; Wang et al., 2012). Simonic and Urbancl (2017) observed that applying a 14400 G magnetic field promotes the formation of $CaCO_3$ as aragonite, whereas mainly calcite is obtained without the use of magnetic fields.

Saksono et al. (2009) investigated the impact of magnetic fields on $CaCO_3$ precipitation in solutions with high and low supersaturation. In supersaturated solutions, the magnetic field enhances ion interactions during circulation in a fluid flow system, thereby reducing $CaCO_3$ precipitation. Jiang et al. (2015) assessed the influence of magnetic field intensity (B) and confirmed that the magnetic field altered the induction time of $CaCO_3$ incrustation under the evaluated conditions. Nevertheless, there is still a need for comprehensive and systematic studies to investigate the effects of the magnetic field on $CaCO_3$ precipitation. Thus, the aim of the present study was to investigate the impact of a constant magnetic field on the formation of mineral salt deposits ($CaCO_3$) on the surface of the walls of thermal appliances used in chemical, oil refining and food processing plants.

One modern approach to preventing sediment formation in thermal appliances involves water treatment using magnets. Through magnetic water treatment, calcium, silicon and magnesium ions dissolved in water lose their capacity to form salts on sorption surfaces. Consequently, insoluble salts remain in suspension, and the sedimentary layer formed on the surface gradually diminishes (Kostyleva et al., 2018).

This method has the advantage of preventing sediment accumulation in heat exchangers without the need for expensive chemicals. The thermal efficiency of devices helps maintain stability and extend the time between repairs. Therefore, this article investigates the impact of the magnetic field on the process of scale formation on the outer surface of the heating element in thermal devices using industrial waters of known general hardness.

Methods and materials

A device for reducing scale formation on heat exchange surfaces using magnetic water treatment and various chemical liquid media was designed and assembled for the experiment. This device is shown in Figure 1.

The device consists of a stainless-steel cylindrical housing 1 surrounded by a plastic pipe 2. Within the cylindrical housing 1, sections of permanent magnets 3 are located at a certain distance from each other (Figure 1), featuring alternating magnetic poles along the length of the casing. The angle (relative to the center of the cylindrical body 1) between each magnetic section is $90\angle^0$. On both sides of the plastic pipe, internal threads 4 are incorporated for attachment to the pipeline.

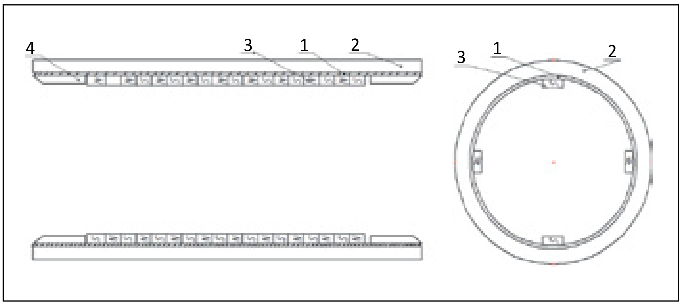

Figure 1. Design of the device for reducing scale formation: 1 – cylindrical body, 2 – plastic pipe, 3 – permanent magnet section, 4 – thread

Rysunek 1. Konstrukcja urządzenia do redukcji kamienia: 1 – korpus cylindryczny, 2 – plastikowa rura, 3 – sekcja magnesów trwałych, 4 – gwint

The device for magnetic treatment of water and various chemical liquid media operates as follows:

Water, flowing through the device, passes through a magnetic field generated by the permanent magnets. Simultaneously, water molecules begin to oscillate during movement under the influence of the Lorentz force. The magnets within the waterway induce resonance in the water. As a result of water treatment under the action of a magnetic field in cold water, the structure of water is disrupted, causing impurities containing calcium and magnesium ions to amalgamate with other impurities, forming a center of crystallization and microcrystallization. This process sets off a chain reaction, preventing the precipitation of calcium and magnesium ions as microcrystals in pipelines and heating systems when heated.

To study the impact of the magnetic field on the process of scale formation on the outer surface of heating elements in thermal devices using industrial waters with a general hardness, experiments were conducted at the "Processes and apparatuses of chemical technology" laboratory of the Institute of General and Inorganic Chemistry of the Academy of Sciences of the Republic of Uzbekistan. The device shown in Figure 1 was used to generate magnetic field. The schematic diagram of the experimental installation and the general scheme of the installation designed for studying the impact of a constant magnetic field on the process of scale formation on the outer surface of heating elements in thermal devices are shown in Figures 2 and 3, accompanied by its corresponding photograph.

The device operates as follows: water from the water supply system is fed through pipes 1 and 2 to heating devices 8 and 9.

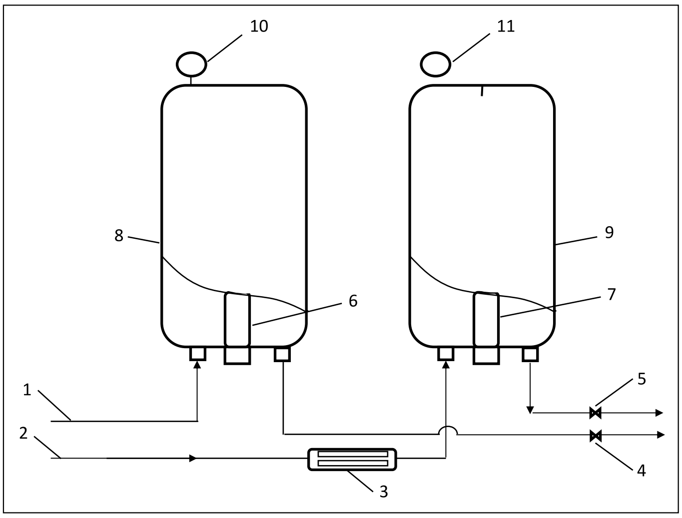

Figure 2. Basic diagram of a device for studying the impact of a constant magnetic field on the water heating process: 1 and 2 – water pipes, 3 –magnetic water treatment device, 4 and 5 – taps for regulating water flow, 6 and 7 – tubular electric heater for water (TEH), 8 and 9 – boilers for water, 10 and 11 – manometers for measuring pressure

Rysunek 2. Schemat ideowy urządzenia do badania wpływu stałego pola magnetycznego na proces podgrzewania wody: 1 i 2 – rury wodne, 3 – magnetyczne urządzenie do uzdatniania wody, 4 i 5 – krany do regulacji przepływu wody, 6 i 7 – rurowy elektryczny podgrzewacz wody (TEH), 8 i 9 – kotły wodne, 10 i 11 – manometry do pomiaru ciśnienia

Figure 3. General view of the experimental setup

Rysunek 3. Ogólny widok układu eksperymentalnego

In the second heating device, the water passes through the magnetic water treatment device 3. The magnetic water treatment device is a pipe with a length of 200 mm and an internal diameter of 32 mm. 16 pieces of NdFeB Neodymium magnet (neodymium-iron-boron) with a size of 0.5 × 10 × 20 are fixed on the inner surface of the pipe. The physical characteristics of the magnet are given in Table 1. The temperature in water boilers is maintained by thermoelectric heaters 6 and 7 (TEH)

Table 1. Physical characteristics of a neodymium magnet

Tabela 1. Właściwości fizyczne magnesu neodymowego

Specifications	Unit of measurement	Meaning
Curie temperature	[°C]	310–380
Maximum operating temperature	[°C]	80–230
Hardness		620
Electrical resistivity	[Om.cm]	$1.8 \times 10^{-4} - 2 \times 10^{-4}$
Density	[g/cm^3]	7.45–7.65
Recoil patency		1.05
The strength of the magnetization region	[Koe]	≥30
Bending force	[MPa]	295–345

with a capacity of 2 kW/h each and a heating surface area of 0.0176 m^2. An automatic temperature-regulating thermostat is installed in the heating element (TEH). Pressure changes in boilers are monitored using manometers 10 and 11. The flow rate of heated water is controlled with taps 4 and 5. The volume of both heating boilers in the pilot plant line is 15 liters. Two different sets of experiments were carried out. In the first case, the water was heated to 70°C and the amount of precipitation formed during heating was measured. In the second case, the water was heated from 30°C to 90°C in 20°C increments and the duration of water heating was 10 days. In the first scenario, the thermostat parameters for switching on and off the supported heating system were set within the range of 69–71°C, whereas in the second scenario, these parameters were adapted relative to the target temperature. For example, at a set temperature of 30°C, the thresholds for turning on and off the thermostat were 29–31°C, and similar adaptations were applied for subsequent temperature levels.

During the experiment, the volumetric flow of water through the pipe was measured with a stopwatch. The constant water flow rate was 3.5 l/min for each heater. Water temperature was controlled by a thermostat installed in an electric heater. The temperature of the heated water at the outlet was measured using a glass thermometer. The limits of the change in water temperature enable the study of scale deposition in electric heaters. Changes in the mass of the scale formed during device heating, dependent on the duration of operation, were assessed through inspections conducted every 30 days.

The heating element (TEH) of the heating boiler shown in Figure 4 was removed from the device and the scale mass was removed from the heating surface. The residual mass from the surface of the heater was immersed in water with citric acid for 25–30 minutes, and the resulting water solution was filtered, added to the starting mass and dried, and then the mass was measured using electronic scales.

Figure 4. Heating element of the heating boiler: 1 – heating element working without magnetic field, 2 – heating element working with magnetic field

Rysunek 4. Element grzejny kotła grzewczego: 1 – element grzejny pracujący bez udziału pola magnetycznego, 2 – element grzejny pracujący pod wpływem pola magnetycznego

Results and discussions

For the computation, industrial water with a total hardness of 4.2 mg-eq/l was used as the subject of the study.

The results of the study of the impact of the magnetic field on the accumulation of mineral deposits on the surface of heating elements in the heating boiler, with water heated to 70°C, are shown in Table 2.

Table 2. The impact of a constant magnetic field on the formation of scale on the surface (176 cm^2) of the heating element with water heated to 70°C

Tabela 2. Wpływ stałego pola magnetycznego na tworzenie się kamienia na powierzchni (176 cm^2) elementu grzejnego przy wodzie podgrzanej do 70°C

Duration of device operation	The amount of precipitation formed	
	during heating without a magnetic field	when heated under the influence of a magnetic field
[days]	[g]	[g]
30	1.07	0.21
60	2.95	0.58
90	5.34	1.02
120	7.68	1.46

Based on the data presented in Table 2, it is evident that the mass of the precipitate formed in the first hot water boiler, without the use a constant magnetic field, was 1.07 g after 30 days of operation. The mass of the mineral sediment increased to 2.95 g during the 60-day period of operation and to 5.34 g during the 90-day period, reaching 7.68 g after 120 days of operation.

In the presence of a constant magnetic field in the heating boiler, the formation of a mineral sediment weighing 0.21 g after 30 days of operation was noted. During the 60-day cycle of operation, the scale mass was 0.58 g, while after 90 days of operation under the influence of a magnetic field, the scale mass was 1.02 g, and after 120 days – 1.46 g. Experimental data indicate that the amount of precipitation (scale) in the heating element of a water heating boiler is, on average, 5 times less when the magnetic field is used compared to the absence of a magnetic field during the heating process.

The graph depicting the change in the time of formation of scale mass on the surface of the heating element in the water heating boiler is shown in Figure 5.

Based on the data presented in Figure 3, it is evident that under the influence of a constant magnetic field, with water heated up to 70°C the mass of scale formed on the surface of the heating element (TEH) decreases by a factor of 5.09 after 30 days, 5.08 after 60 days, 5.23 after 90 days, and 5.26 after 120 days.

Additionally, an investigation into the impact of the temperature of the heated water over a 10-day period on the scale formation on the surface of the heating element has been conducted, and the results are presented in Table 3.

Based on the data provided in Table 3, over a 10-day heating period at specified temperatures, the sediment mass accumulation, with water heated under the influence of a magnetic field, exhibits a reduction by a factor of 4.25 at 30°C, of 4.88 at 50°C, of 5.1 at 70°C, and of 2.85 at 90°C compared to the conventional condition. The variable dynamics suggest that, as the water

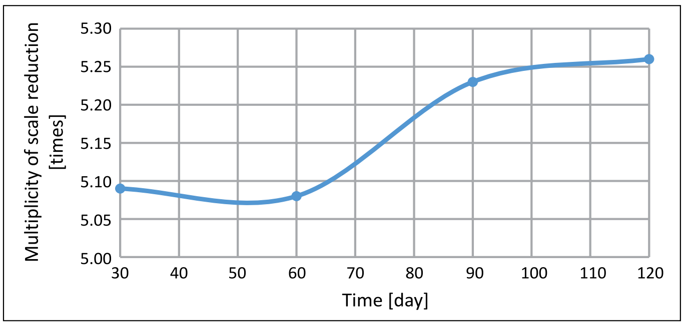

Figure 5. Impact of a constant magnetic field on the formation of scale mass on the surface of a heating element in a water heating device with water heated to 70°C

Rysunek 5. Wpływ stałego pola magnetycznego na tworzenie się kamienia na powierzchni elementu grzejnego urządzenia podgrzewacza wody podczas podgrzewania wody do 70°C

Table 3. Impact of the temperature of the heated water over a 10-day period on the formation of scale on the surface of the heating element

Tabela 3. Wpływ temperatury podgrzewanej wody na tworzenie się kamienia na powierzchni elementu grzejnego w okresie 10 dni

Water temperature	The amount of precipitation formed	
	during heating without a magnetic field	when heated under the influence of a magnetic field
[°C]	[g]	[g]
30	0.51	0.12
50	0.83	0.17
70	1.02	0.20
90	1.37	0.48

temperature is increased to 70°C, the magnetic field continues to exert an inhibitory effect on the precipitation of mineral salts in water. When the temperature rises above 90°C, the effect of a constant magnetic field on the accumulation of minerals in water on the surface of the heating element decreases.

Conclusions

When feed water passes through a constant magnetic field in heating devices used in the chemical oil refining and food industries, compounds holding calcium and magnesium ions in water amalgamate to form a center of crystallization and microcrystallization. As a result, the formation of mineral scale is prevented, and the use of expensive chemicals is avoided. The devices achieve peak thermal efficiency due to the stable operation of the apparatus.

Thus, both computational and experimental studies on the process of scale formation in water-heating boilers operating within temperature range from 30°C to 70°C shows that the formation of scale on the surface of the heating element in a water heating boiler decreases, on average, by a factor of 5 when a constant magnetic field is integrated into the water flow path. However, as the temperature increases beyond 90°C, the rate of scale formation gradually increases.

References

Al Helal A., Soames A., Iglauer S., Gubner R., Barifcani A., 2019. The influence of magnetic fields on calcium carbonate scale formation within monoethylene glycol solutions at regeneration conditions. *Journal of Petroleum Science and Engineering*, 173: 158–169. DOI: 10.1016/j.petrol.2018.09.100.

Bannikov V.V., 2004. Elektromagnitnaya obrabotka vody. *Ekologiya Proizvodstva*, 4: 25–32.

Cefalas A.C., Kobe S., Drazic G., Sarantopoulou E., Kollia Z., Strazisar J., Meden A., 2008. Nanocrystallization of $CaCO_3$ at solid/liquid interfaces in magnetic field: a quantum approach. *Applied Surface Science,* 254(21): 6715–6724. DOI: 10.1016/j.apsusc.2008.04.056.

Chang M., Tai C.Y., 2010. Effect of the magnetic field on the growth rate of aragonite and the precipitation of $CaCO_3$. *Chemical Engineering Journal,* 164(1): 1–9. DOI: 10.1016/j.cej.2010.07.018.

Chibowski E., Szcześ A., 2018. Magnetic water treatment – a review of the latest approaches. *Chemosphere*, 203: 54–67. DOI: 10.1016/j.chemosphere.2018.03.160.

Fedotkin I.M., Lipsman V.S., 1972. Intensifikatsiya teploobmena v apparatakh pishchevykh proizvodstv. *Pishchevaya promyshlennost'*, 1–240.

Glater, J., York, L., Campbell, K.S., 2012. Principles of Desalination. *Academic Press, Inc, London*.

Ismailov O.Y., Khudoyberdiyev A.A., Khurmamatov A.M., 2017. Issledovaniye zavisimosti koeffitsiyenta teploperedachi ot tolshchiny nakipi i rezhima dvizheniya nagrevayemoy neftegazokondensatnoy smesi v gorizontal'noy trube. *Nauchno--Tekhnicheskiy Zhurnal «Neftepererabotka i Neftekhimiya», Moskva*, 2: 42–45.

Ismailov O.Y., Ramonov T.Z., 2017. Izucheniye usloviya obrazovaniya otlozheniy v trubakh teploobmennykh apparatakh. *Nauchno--Tekhnicheskiy Zhurnal, «Khimicheskaya Promyshlennost'». Sankt-Peterburg*, 2: 74–78.

Ismoilov M.Kh., Ismailov O.Y., 2022. The effect of the magnetic field on the accumulation of scale mass in heat exchange devices. *Materials of the Republican scientific and practical conference on the topic problems in the Chemical Technology, Chemical and food industries and ways to eliminate them in the conditions of integration of Science and production, Namangan, 03-04.06.2022*: 213–215.

Jiang L., Zhang J., Li D., 2015. Effects of permanent magnetic field on calcium carbonate scaling of circulating water. *Desalination and Water Treatment*, 53: 1275–1285. DOI: 10.1080/19443994.2013.850450

Khormali A., Sharifov A.R., Torba D.I., 2018. Increasing efficiency of calcium sulfate scale prevention using a new mixture of phosphonate scale inhibitors during waterflooding. *Journal of Petroleum Science and Engineering*, 164: 245–258. DOI: 10.1016/j.petrol.2018.01.055.

Khurmamatov A.M., Auesbaev A.U., 2023. Analysis of the operating mode of the existing desorber and its modernization using additional contact devices. *Nafta-Gaz*, 79(6): 412–419. DOI: 10.18668/NG.2023.06.05.

Kobe S., Drazic G., Cefalas A.C., Sarantopoulou E., Strazisar J., 2002. Nucleation and crystallization of $CaCO_3$ in applied magnetic fields. *Crystal Engineering*, 5(3–4): 243–253. DOI: 10.1016/S1463-0184(02)00035-7.

Kolesnikov V.A., Nechayev Y.G., 1980. Teplosiloviye khozyaystvo sakharnykh zavodov. *Pishchevaya Promishlennost'*, 1–392.

Koshoridze S.I., Levin Yu.K., 2009. Fizicheskaya model' snizheniya nakipeobrazovaniya pri magnitnoy obrabotke vody v teploenergeticheskikh ustroystvakh. *Teploenergetika*, 4: 66–68.

Kostyleva S.S., Dzhumabayev Kh.K., Tyusenkov A.S., 2018. Vliyaniye elektrokhimicheskoy aktivatsii vody na soleotlozheniye. *Neftegazovoye Delo*: 16(4): 89–95. DOI: 10.17122/ngdelo--2018-4-89-96.

Kozic V., Hamler A., Ban I., Lipus L.C., 2010. Magnetic water treatment for scale control in heating and alkaline conditions. *Desalination and Water Treatment*, 22(1–3): 65–71. DOI: 10.5004/dwt.2010.1549.

Mosin O.V., Ignatov I., 2011. Struktura vody i fizicheskaya real'nost'. *Soznaniye i Fizicheskaya Real'nost'*, 16(9): 16–32.

Ochkov V.F., 2006. Magnitnaya obrabotka vody: istoriya i sovremennoye sostoyaniye. *Energosberezheniye i Vodopodgotovka*, 2: 23–29.

Prisyazhnyuk V.Y., 2004. Zhestkost' vody: sposoby umyagcheniya i tekhnologicheskiye skhemy. *SOK, Rubrika Santekhnika i Vodosnabzheniye*, 11: 45–59.

Reis M.I.P., Da Silva F.D.C., Romeiro G.A., Rocha A.A., Ferreira V.F., 2011. Deposição mineral em Superfícies: Problemas e oportunidades na indústria do Petróleo. *Revista Virtual de Quimica*, 3(1): 2–13. DOI: 10.5935/1984-6835.20110002.

Saksono N.Y., Bismo S., Soemantojo R.W., Manaf A. 2009. Effects of pH on calcium carbonate precipitation under magnetic field. *Makara Journal of Technology*, 13(2): 79–85. DOI: 10.7454/mst.v13i2.479.

Shchelokov Ya.M., 2002. O magnitnoy obrabotke vody. *Novosti Teplosnabzheniya*, 8(24): 41–42.

Simonic M., Urbancl D., 2017. Alternating magnetic field influence on scaling in pump diffusers. *Journal of Cleaner Production*, 156: 445–450. DOI: 10.1016/j.jclepro.2017.04.080.

Sohaili J., Shi H.S., Baloo L., Zardari N.H., Ahmad N., Muniyandi S.K., 2016. Removal of scale deposition on pipe walls by using magnetic field treatment and the effects of magnetic strength. *Journal of Cleaner Production*, 139: 1393–1399. DOI: 10.1016/j.jclepro.2016.09.028.

Vazirian M.M., Charpentier T.V.J., Penna M.O., Neville A., 2016. Surface inorganic scale formation in oil and gas industry: as adhesion and deposition processes. *Journal of Petroleum Science and Engineering*, 137: 22–32. DOI: 10.1016/j.petrol.2015.11.005.

Vermeiren T., 1958. Magnetic treatment of liquids for scale and corrosion prevention. *Anti-Corrosion Methods and Materials*, 5(7): 215–219. DOI: 10.1108/eb019464.

Wang S.S.S., Chang M.-C., Chang H.-C., Chang M.-H., Tai C.Y., 2012. Growth Behavior of Aragonite under the Influence of Magnetic Field, Temperature, and Impurity. *Industrial & Engineering Chemistry Research*, 51(2): 1041–1049. DOI: 10.1021/ie2016015.

Zendehboudi S., Shafiei A., Bahadori A., James L.A., Elkamel A., Lohi A., 2014. Asphaltene precipitation and deposition in oil reservoirs – technical aspects experimental and hybrid neural network predictive tools. *Chemical Engineering Research and Design*, 92(5): 857–875. DOI: 10.1016/j.cherd.2013.08.001.

Oybek Yuliboyevich ISMAILOV, Sc.D.
Leading researcher at the Institute of General and Inorganic Chemistry of the Academy of Sciences of the Republic of Uzbekistan
77a Mirzo Ulugbek Ave., 100170 Tashkent, Uzbekistan
E-mail: *ismoilovnmpi@mail.ru*

Abdugaffor Mirzaabdullaevich KHURMAMATOV, Sc.D.
Head of laboratory at the Institute of General and Inorganic Chemistry of the Academy of Sciences of the Republic of Uzbekistan
77a Mirzo Ulugbek Ave., 100170 Tashkent, Uzbekistan
E-mail: *gafuri_19805@mail.ru*

Mirzaakbar ISMOILOV, M.Sc.
Basic doctoral student at the Institute of General and Inorganic Chemistry of the Academy of Sciences of the Republic of Uzbekistan
77a Mirzo Ulugbek Ave., 100170 Tashkent, Uzbekistan
E-mail: *imirzaakbar@gmail.com*

Alisher Usnatdinovich AUESBAEV, M.Sc.
Basic doctoral student at the Institute of General and Inorganic Chemistry of the Academy of Sciences of the Republic of Uzbekistan
77a Mirzo Ulugbek Ave., 100170 Tashkent, Uzbekistan
E-mail: *alisherauesbaev@gmail.com*

Usnatdin Auesbaevich UTEGENOV, M.Sc.
Assistant at the Karakalpak State University named after Berdakh
1 Ch. Abdirov Ave., 230112 Nukus, Uzbekistan
E-mail: *Usnatdin@mail.ru*