Minimizing Deposit Formation in Industrial Fluid Heat Exchangers

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Abstract. This paper considers the most urgent problem of today related to decreasing deposit formation in fluid heat exchangers used in industry. The authors discuss the categories of external and internal deposition, identify the causes of their formation and impact on the efficiency of heat exchange equipment. The paper reveals the causes of changes in the heat transfer coefficient of heat exchangers. Special attention is given to techniques designed to prevent or mitigate fouling in heat exchangers. Based on the analysis of Russian and foreign studies, the most popular methods for cleaning heat exchangers, their positive and negative aspects have been identified. The authors have concluded that attention should be paid not only to cleaning heat exchangers, but also to preventing their fouling.

1. Introduction
Fluid heat exchangers are widely used in chemical, petrochemical and other industries. Fluid heat exchangers come in different forms, the most popular of which are shell and tube and plate type heat exchangers. Their fouling has been extensively investigated and remains one of the most urgent problems. The intensive deposit formation on heat exchange surfaces causes a major decrease in the thermal conductivity of heat exchangers. As a consequence, the heat transfer is deteriorated that increases the energy consumption for production, and without appropriate measures, the equipment may malfunction. To minimize deposit formation in heat exchangers, Russian and foreign studies are reviewed. This task is important in solving problems of design and management of production facilities for complex automation of chemical enterprises using modern achievements in the field of information technology, in particular the integration of automated enterprise management systems with automated control systems for individual technological processes.

2. Deposition types
In fluid heat exchangers there are two types of deposit formations: internal and external. Hard deposits on heat exchange surfaces are presented by scale and mineral deposits. Scale is a hard deposit formed on the inner walls of heat exchangers in which there occur heating or evaporation of water containing salts. The thermal conductivity of scale is lower than that of the steel heat exchanger. Therefore, even a thin scale layer creates a significant thermal resistance which can lead to local overheating and deterioration.
Mineral deposits (insoluble salts, scale, metal corrosion products, mechanical impurities of metal and sand particles) are not normally formed at heat exchanger operating temperatures. They are formed due to salt crystallization processes. Crystallization centers may appear on the heat exchanger surfaces because of their contamination or thermal effects. Then, crystals grow due to diffusion of new molecular substances. After the diffusion has been hindered, the deposits become dense. Hence, the mineral deposits are formed with layers.

External deposits are subdivided depending on:
- the place of formation (deposits from platen heating surfaces and deposits from convective heating surfaces),
- temperature zones of formation (high and low temperatures),
- strength, hardness and density (loose connected, fused),
- chemical and mineralogical composition (alkaline, silicate, iron, copper),
- the tube perimeter location (front, back).

Many analytical techniques are used to characterize deposit analysis. Typical methods include x-ray diffraction analysis, x-ray spectrometry, and optical emission spectroscopy [1].

To improve heat exchanger efficiency, antiscalant development and prevention of precipitation formation, it is important to study the mineral composition of salt deposits, the factors affecting the speed and intensity of their formation, and their removal methods [2, 3]. The factors are as follows: quality and temperature of the working fluid [4], surface roughness of the heat transfer, materials of heat transfer surfaces [5].

The causes of fouling and its effect on the heat transfer coefficient, temperature differences for shell and tube and plate type heat exchangers are studied [6].

S. V. Korneev et al. [7] found out that the main reason for changing the heat transfer coefficient was the thermal resistance of fouling. The heat transfer coefficient of the heat exchanger is changed due to:
- accumulation of contaminants on the tube surface,
- changes in the flow regime for the thermal fluid,
- the initial temperature of thermal fluid streams,
- heat loss from the outer surface of the device,
- changes in the physical properties of streams due to changes in the composition of thermal fluids.

C. H. Gilmour [8] informed that the degradation of heat transfer performance due to fouling in shell and tube heat exchangers occurs mostly due to poor shell-side design.

A. M. Demin et al. [9] presented the heat exchanger performance on the diesel hydrotreater, the dependence of coking on the quantity of dissolved oxygen in the raw material, revealed problems and proposed their solutions.

Scale formation in the heat exchanger is affected by water hardness. K. Kusaiyev et al. [10] came to the conclusion that crystallization processes of calcium and magnesium carbonates played the leading role in the formation of salt deposits.

The authors conducted a comparative evaluation of methods and water treatment devices [11, 12, 13], studied chemical and physical removal methods of calcium and magnesium salts from water: reagent, ion exchange and membrane methods [14, 15, 16], magnetic water treatment [17, 18]. It is concluded that the effectiveness of equipment protection from scale formation increases with increasing magnetic field intensity; antiscale equipment protection is less in open systems than in closed cycles [19].

The study of the mineral deposit composition allows to select effective chemicals used as antiscales (antiscalants) [20].

The heat exchanger precipitation represents polynmineral mixture, which involves the oxide, hydroxide, phosphate, carbonate and aluminosilicate mineral phases. Carbonate phases that play a dominant role are better represented by calcite and aragonite than by vaterite. Within a macromineral
meaning salt deposits are closer to travertines – natural formations formed by the discharge of natural waters. The formation of the mineral salt deposit composition is affected by temperature, ionic strength of the solution, divalent cations, some anions, organic matter [21].

S. I. Koshoridze and Y. K. Levin [22] found out that scaling in the form of calcite is energetically more profitable than aragonite.

M. I. Davidzon [23] proposed a mathematical model for calculation of scale formation in tubes at a constant wall temperature.

If water treatment is insufficient or is not done, the heat exchanger has to be cleaned. Before attempting to clean a heat exchanger it should be carefully examined.

The following factors are of great importance for selecting a cleaning method:
- degree of fouling,
- nature of the foulant, known through deposit analysis,
- the compatibility of the heat exchanger material and system components in contact with the cleaning chemicals,
- regulations against environmental discharges,
- accessibility of the surfaces for cleaning,
- cost factors [1].

3. Methods for fouling removal
Various methods can be used to remove fouling. They include:
- Mechanical cleaning.
- Chemical cleaning.
- Hydromechanical cleaning.
- Hydrochemical cleaning.
- Hydrodynamic cleaning.
- Electromagnetic water treatment.
- Ultrasonic cleaning.

The need to deal with deposits led to the search for the most suitable cleaning methods for heat exchangers to prevent precipitation forming metal carbonates. For this purpose dissolution kinetics of calcium carbonate as the main component of these deposits is studied [24].

In severe cases, mechanical cleaning of heat exchangers is applied. Contaminated parts are removed from the heat exchanger, its blocks or plates are washed out by a water stream under high pressure.

The merits of mechanical cleaning methods include simplicity and ease of operation, and capability to clean completely blocked tubes. However, the demerits of this method may be due to the damage of the equipment, particularly tubes, and the use of high pressure water jet or air jet may cause injury or accidents to personnel engaged in the cleaning operation [1].

Chemical cleaning is used very frequently to clean heat exchangers. Dismountable chemical cleaning makes it possible to eliminate almost all the foulants. However, this cleaning method is laborious, expensive, and there is a danger of equipment damage from corrosion due to reactions of surface materials with the cleaning fluid.

Biofouling (deposition and/or growth of material of biological origin on the heat transfer surface) [25] can be removed by chemical treatment or mechanical cleaning processes. Biocides (chlorine, chlorine dioxide, bromine, ozone and surfactants) are used in chemical treatment methods. Other effective cleaning methods include thermal shock or hot water treatment, and a less known method is ultraviolet radiation [26].

Hydromechanical cleaning is performed by rotating flexible metal hoses with carbide nozzles. The cleansing tool is a jet of water supplied by the UHP pump using special tools (nozzles). To prevent the formation of deposits on heating surfaces of heat exchangers the hydrodynamic properties of the thermal fluid flow are used [27]. The method of continuous hydrodynamic cleaning of plate heat
exchangers with spherical dimples is developed and experimentally proved [28]. The advantage of hydromechanical cleaning is less complexity.

Methods for washing off (dissolving) deposits in heat exchange channels without employing chemical reagents are proposed [29].

A. M. Pritchard [30] divided mechanical methods into two categories according to their ways of action:

- Brute force methods such as high-pressure jets, lances, drills.
- Mild methods such as brushes and sponge balls.

H. M. Mueller-Steinhagen [31] stated that several mechanical methods had been developed recently. The following mechanisms provide a basis for the modern methods of heat exchanger cleaning:

- Breakage of deposits during brief overheating due to differential thermal expansions of heat transfer surface and deposits.
- Mechanical vibration of the heat transfer surfaces.
- Acoustical vibration of the surface.
- Increased shear stress at the fluid/deposit interface.
- Reduced stickiness of the heat transfer surface [32].

Most liquid-side fouling mitigation techniques have been developed for shell and tube heat exchangers. The relevant techniques include:

- Increase in flow velocity.
- Reversal of flow direction.
- Heat transfer surface, such as surface roughness and surface materials.
- Fluidised bed heat exchangers.
- Pulsating flow.
- Turbulence promoters.
- Transport of cleaning devices through tubes [32].

The deposits which slightly adhere to the surface can be removed by increasing the flow velocity. H. M. Mueller-Steinhagen and J. Middis [33] stated that alumina deposits were removed completely when the flow velocity was increased for a short period of time after a fouling run.

At a regular interval of time, the reversal of flow direction on the heat transfer surface could be another effective method of reducing fouling. However, this technique needs several modifications in the existing set-up. Mitigation of fouling by increasing the flow velocity could be more effective than reversal of flow direction [31, 32].

Surface material and surface roughness play an important role in fouling mitigation. Lowering the surface roughness retards the adhesion of deposits. Lower deposition rate also experienced with lowering surface energy of the material of heat exchanger. Using inert particles is an effective way of reducing or even eliminating fouling completely as practiced in fluidized bed heat exchangers. Pulsating flow in heat exchangers is a strategy to increase the level of turbulence [32, 34, 35]. Actually, heat transfer coefficient increases with the enhancement of deposit removal. Higher heat transfer reduces fouling by reducing the interface temperature which is beneficial for certain fouling mechanism such as crystallization fouling of inverse solubility salts. The higher level of turbulence augments the deposit removal rate [32].

Fracture of deposits by fatigue is enhanced by higher turbulence due to pulsation resulting in increasing removal rates. In general, the deposition rate of fouling phenomena depends on the thickness of viscous and thermal sub-layers [1]. H. M. Mueller-Steinhagen [31] found out that by inserting turbulence promoters inside tubes or by using tube corrugations, the heat transfer coefficient can be increased by a factor of 2 to 15 by reducing the thickness of average thermal boundary layer. Turbulence promoters may reduce both the crystallisation and reaction fouling. Particulate fouling will be enhanced if particulate or fibrous material already exists in the solution [32].
J. Middis [36] reported fouling mitigation by adding natural fibre in the supersaturated solutions of concentration 3.6 g/L CaSO4. He also found out that the rate of CaSO4 fouling on heated metal tube surface decreases with the increase of fibre concentration in the fouling solution. S. N. Kazi [37] also obtained similar results by adding different types and concentrations of natural fibre in supersaturated solutions of CaSO4.

Based on the cleaning in-place system, such devices as boosters are used for chemical cleaning of heat exchangers. Cleaning agents circulating under certain pressure and temperature are introduced into the system. The effectiveness of chemical cleaning depends on the correct selection of reagents. To do this, determine the type of scale, design features of the system, the material of the heat exchanger. Strong acids are mainly used. To clean the heat exchangers from scale with the composition of calcium carbonate, the nitric acid solution is effective; sulfamic acid is used as an acidic cleaning agent for metal oxides. Orthophosphoric acid is used in limited industrial applications. Hydrochloric acid is used in the dissolution of carbonate scale and phosphate sludge. It removes silicate deposits poorly and almost does not dissolve sulfate scale. Iron oxides (magnetite and hematite) are slightly soluble in it, and wustite is very soluble. Acid is corrosive to metals and alloys, it is unacceptable to use it for elements of austenitic steels. If hydrochloric acid concentration is more than 4.5% by weight, it increases the cleaning rate with increasing temperatures from 40 °C to 50 °C [38].

Various researchers justified their selection of an optimal reagent for efficient cleaning. A. V. Denisova et al. [39] offered an acid-generating aqueous solution of aluminum dichloride hydroxide consisting of AlCl3, Al(OH)Cl2, Al(OH)2Cl.

At present, scale inhibitors (antiscales) as reagents including organophosphorus acids or their salts (phosphonates) are widely used. Organic antiscales are polymers containing anionic, cationic or nonionic carboxylic, hydroxyl, sulfonic, phosphonic functional groups.

The interaction of antiscales with crystal surfaces results in the ability of various compounds to complexing. In some cases, when using phosphonates they observe decreasing heat exchanger performance due to tube fouling by carbonate deposits [40].

According to H. Al-H. Ibrahim, the chief techniques normally utilised are either chemical or mechanical cleaning, but other procedures may sometimes be employed for some specific applications such as ultrasonic cleaning, which is a more recent procedure [41].

T. R. Bott [42] stated that the additives used act in different ways, such as sequestering agents, threshold agents, crystal modifiers and dispersants. Some of the common water additives are EDTA (sequestering agent), polyphosphates and polyphosphonates (threshold agents) and polycarboxylic acid and its derivatives (sequestering and threshold treatment). Sequestering agents such as EDTA complex strongly with the scaling cations such as Ca ++, Mg ++, and Cu ++ in exchange with Na +, thus preventing scaling as well as removing any scale formed previously. They are used effectively as antiscalants in boiler feed water treatment. D. H. Troup and J. A. Richardson [43] found out that their use is uneconomical when hardness levels are high.

Polyphosphates and polyphosphonates as threshold agents are also used to reduce scaling in boilers and cooling water systems. T. R. Bott [42] noted that they prevent the formation of nuclei, thus preventing the crystallisation and mitigate fouling. Very small quantities of these agents are effective in reducing scaling from supersaturated salt solutions.

Crystal modifying agents distort the crystal habit and inhibit the formation of large crystals. The distorted crystals do not settle on the heat transfer surface, they remain suspended in the bulk solution. If their concentration increases beyond a certain limit, particulate fouling may take place. This is prevented either by using techniques to minimise particulate fouling or using dispersing agents along with crystal modifying agents [32].

Although crystallisation fouling may not be prevented completely using additives, the resulting crystalline deposits are different from those formed in the absence of any additives. The layer loses its strength and can be removed easily. By controlling pH, crystallisation fouling can furthermore be
minimised. The solubility of deposit forming components usually increases with decreasing pH. In many water treatment plants, sulphuric acid is added to maintain a pH between 6.5 and 7.5 [32, 44]. Seeding is used to reduce crystallisation fouling. This method involves addition of seeds to the scaling fluid. Crystallisation occurs on these seeds rather than on the heat transfer surface. Calcium sulphate seeds are used to avoid calcium sulphate scaling [32, 45].

To mitigate particulate fouling by chemical means, dispersants are used to reduce the surface tension of deposits. It helps in disintegrating the suspended particles into smaller fragments that do not settle so readily. Addition of certain chemicals can slow down or terminate chemical reactions. Dispersants are very helpful in keeping the foulants away from the surface. Some particles such as corrosion products may act as catalysts. Chemical reaction fouling could be suppressed by reducing the number of these particles. Corrosion inhibitors (chromates and polyphosphates) can be used to reduce corrosion fouling [44]. Normally, a passivating oxide layer is desired to prevent corrosion of the surface. Corrosion fouling may promote other fouling mechanisms, for instance, higher roughness of the corroded surface may enhance crystallisation fouling. The corrosion products may act as catalysts and promote chemical reaction fouling and also augments particulate fouling by depositing on the heat transfer surface [32].

Mitigation of fouling by chemical methods has several drawbacks. Fouling and corrosion inhibitors usually contain considerable amount of chlorine, bromine, chromium, zinc etc. Therefore, their concentration has to be monitored carefully. Treatment of fluid released from the plant to natural waterways is necessary to prevent harmful effects. Higher concentrations can be used in closed systems but overdosing may have negative effects and some components may precipitate. Using different additives at the same time may result in dangerous chemical reactions. Some additives have limited life and some degrade with time and loose activity [32].

Chemical cleaning offers the following advantages over the mechanical cleaning:

- Uniform cleaning and sometimes complete cleaning.
- Sometimes chemical cleaning is the only possible method.
- No need to dismantle the unit, but it must be isolated from the system.
- Capable of cleaning inaccessible areas.
- Moderate cleaning cost and longer intervals between cleaning [1].

However, there are some disadvantages of chemical cleaning. Chemicals used for cleaning are often hazardous to use and require elaborate disposal procedures. Noxious gases can be emitted from the cleaning solution due to unexpected reactions. Chemical cleaning corrodes the base metal and the possibility of excess corrosion cannot be ruled out. Complete washing of the equipment is a must to eliminate corrosion due to residual chemicals [1].

As the scale removal by chemical cleaning reagents is labour-intensive, electromagnetic effects are considered to be an effective and low-cost removal method for deposits of calcium and magnesium salts [44, 46].

G. Parkinson and W. Price [47] pointed out the significant reduction in fouling by the magnetic treatment as it helps in precipitating the salts. These salts stay suspended in the bulk liquid and are removed later. On the other hand, D. Hasson and D. Bramson [48] stated that there is no effect of magnetic treatment at all on fouling. They observed that magnetic treatment neither decreased nor increased the rate of scaling. The nature of the deposits also remained unchanged. H. M. Mueller-Steinhagen [31] found out that magnetic mitigation devices in some cases increased fouling.

Thus, there are different scientific points of view concerning magnetic treatment effects.

D. M. Runov and A. G. Laptev [17] considered the electromagnetic water treatment as a reagent-free method for reducing the amount of scale and increasing the cooling efficiency of high-temperature gas flows. They developed a method for determining the effect of electromagnetic waves on the cooling efficiency of hydrocarbon gas in some areas of settling particles on experimental glass plates. It was found out that the electromagnetic effect is influenced by the iron content in the treated water.
To improve industrial water treatment by a constant electric field, antiscale devices are developed and their industrial safety is studied [49].

V. S. Zverev and R. A. Akhmedzhanov [50] stated that the efficiency of ultrasonic cleaning scale deposits may be increased by technological methods that reduce its sound resistance. Technological methods should be aimed at the formation of physical destruction factors. Sound resistance factors depend on the operating frequency and have low values in the frequency range of 1-80 kHz.

4. Conclusion
The fouling phenomenon is an unavoidable part of production processes. In many industrial applications, fouling occurs despite good design, effective operation and maintenance. Thus, heat exchangers and associated equipment must be cleaned so that they could continue to operate efficiently. The frequency of cleaning depends on the severity of the fouling problem. In some instances, cleaning can be carried out twice yearly or annually, according to the periodical maintenance program, and in other cases, frequent cleaning may be required monthly or quarterly [1]. There are different methods for fouling removal. However, all these methods require costly safe system shutdowns after a longer period of low heat exchanger efficiency. Effective prevention measures, including various control and maintenance techniques, should be taken to minimize the probability of deposit formation in fluid heat exchangers.

5. References
[1] Awad MM 2011, Jan. Fouling of heat transfer surfaces [Online] Available: http://www.intechopen.com/books/
[2] Gunko I V, Tarasenko N V, Nikulin N Y 2015 Factors affecting the rate of scale formation International science and technology conference of young scientists (BSTU, Belgorod) pp 1040-1044
[3] Fesak D V, Litvinenko A A 2017, Jun. Problem of heat exchanger tube fouling and methods for its solution [Online] Available: http://web.snauka.ru/issues/
[4] Suss A G, Panov A V, Lukyanov I V, Kuznetsova N V, Kuvyrkina A M, Damaskin A A 2008 Influence of mineral deposits on thermodynamic properties of heat exchangers Metallurg 11 pp 89-92
[5] Sheveiko A B, Bublikov R Z 2002 Influence of surface material on deposits in heat exchange equipment of process water systems Thermal Engineering 7 pp 62-66
[6] Galkovskiy V A, Chupova M V 2017, Jun. Analysis of decreasing the heat transfer coefficient of heat exchangers due to the surface fouling [Online] Available: http://naukovedenie.ru/PDF/41TVN217.pdf
[7] Kornee S V, Demin A M, Demin M A, Sorokin V N, Kabakov A N 2012 Improving the efficiency of heat exchangers, compressors and process equipment Vestnik SibADI vol 3 25 pp 18-21
[8] Gilmour C H 1965 No fouling- no fouling Chem. Eng. Progr. vol 61 7 pp 49-54
[9] Demin A M, Demin M A, Malenkhik V S, Kornee S V 2015 Deposit removal techniques for heat exchangers of diesel hydrotreaters World of Oil Products The Oil Companies’ Bulletin pp 32-37
[10] Kusaiyinov K, Nussupbekov B R, Turlybekova R S 2009 Mineral growths in heat exchange equipment of technical water systems Scientific Review 2 pp 69-72
[11] Khmelkova D L, Ivanshchikov Y V 2015 Scale removal from heat transfer surfaces Engineers – the future of innovation economy in Russia 1-1 pp 124-127
[12] Myakinkov A G 2001 Antiscale devices for cleaning heat exchangers Food and Processing Industry. Abstract Journal 1 pp 51
[13] Lavrenchenko G K, Kopytin A V, Dmitriev N M 2014 Analysis of methods for cleaning heat exchangers from various types of fouling Industrial Gases 5 pp 52-61
[14] Hamer P, Jackson J, Thurston E F 1968 Industrial water treatment practice (M.: Publishing literature on construction) 418 p
[15] Vysotsky S P 1989 Ion-exchange membrane and water treatment technology in power industry (K.: Tehnika) 176 p
[16] Dytynersky Y I 1975 Membrane separation processes of liquid mixtures (M.: Chemistry) 232 p
[17] Runov D M, Laptev A G 2015 Efficiency improvement of heat exchangers by the rational choice of the range of frequencies of electromagnetic water treatment Teploenergetika vol 62 5 pp 374-377
[18] Buerger A 1995 Physikalische Wasserbehandlung gegen Kalk und Rost” Entsorg. Prax. 3 pp 57-58
[19] Gorban Y N, Cherkasova T G, Nevedrov A V 2016 Removal methods for calcium and magnesium salts from water Bulletin of Kazbass State Technical University 2 pp 126-135
[20] Potapov S S 2003 Mineralogy of scales in wells and other oil production equipment of oil fields in Western Siberia Abstract of PhD Thesis in Geology and Mineralogy (Yekaterinburg) 22 p
[21] Amjad Z 2014 Mineral scales in biological and industrial systems Boca Raton, FL: Taylor & Francis Group 432 p
[22] Koshoridze S I, Levin Y K 2016 Analysis of scale salt deposits on the walls of the heat exchanger Proceedings of the XI International conference on nonequilibrium processes in nozzles and jets (M.: MAI) pp 526-527
[23] Davidzon M I 2007 Formation of scale inside the tubes of heat exchangers at a constant wall temperature Teploenergetika vol 54 9 pp 739-742
[24] Artamonova I V, Gorichev I G, Chernyshova E N, Godunov E B, Rusakov S M 2013 Development of the experimental method for calcite dissolution processes and calculation of kinetic parameters Scientific and technical bulletin of the Volga Region 6 pp 61-65
[25] Kakaç S, Liu H, Pramanjaroenkij A 2012, Mar. Heat exchangers: selection, rating, and thermal design, third edition [Online] Available: https://www.amazon.co.uk/
[26] Chenoweth J M 1989 General design of heat exchangers for fouling conditions Fouling Science and Technology. Kluwer, Dordrecht pp 477-494
[27] Mikhailov I 2013, Apr. Self-cleaning heat exchangers [Online] Available: https://aquatherm.ru/articles/articles_288.html
[28] Takmovtsev V V, Ilyinkov A V, Shchukin A V, Zaripov I S 2016 Hydrodynamic self-cleaning of plate heat exchangers with spherical dimples Izvestiya vysshikh uchebnych zavedenii. Problemy Energetiki 9-10 pp 56-65
[29] Kamenetsky B Y 2010 Conditions for dissolution of boiler scale Teplofizika Vysokikh temperatur vol 48 2 pp 318-320
[30] Pritchard A M 1988 Cleaning of fouled surfaces: a discussion Fouling Science and Technology, NATO ASI Series, Series E: Applied Science pp 721-726
[31] Mueller-Steinhagen H M 1993 “Fouling: the ultimate challenge for heat exchanger design The sixth International Symposium on Transport Phenomena in Thermal Engineering (Seoul, Korea)
[32] Kazi S N 2012, Mar. Fouling and fouling mitigation on heat exchanger surfaces [Online] Available: http://www.intechopen.com/books/
[33] Mueller-Steinhagen H M, Middis J 1989 Particulate fouling in plate heat exchangers Heat Transfer Engineering, vol10 4 pp 30-36
[34] Ludlow J C, Kirwan D J, Gainer J L 1980 Heat transfer with pulsating flow Chemical Engineering Communications 7 pp 211-218
[35] Karamerican O E, Gainer J L 1979 The Effect of pulsations on heat transfer Industrial Engineering Chemistry Fundamentals vol 18 1 pp 11-15
[36] Middis J 1994 Heat transfer and pressure drop for flowing wood pulp fibre suspensions PhD thesis, Chemical and Materials Engineering The University of Auckland: Auckland (New Zealand)
[37] Kazi S N 2001 Heat transfer to fibre suspensions-studies in fibre characterisation and fouling mitigation PhD thesis, Chemical and Materials Engineering, The University of Auckland: Auckland (New Zealand)

[38] Uzhakhova L Y, Sultygova Z H, Archakova R D, Kitieva L I, Martazanova R M, Yevloyeva A Y 2016 Research and choice of an optimal agent for surface cleaning from scale Bulletin of Modern Science 9(21) pp 19-24

[39] Denisova A V, Glushchenko V N, Zagumennykh D V 2009 New descaling reagent Energy Saving and Water Treatment 3(59) pp 32-34

[40] Balaban-Irmenin Y V, Rubashov A M, Dumnov V P 1996 Antiscale problems in heat supply systems Industrial Power Engineering 4 pp 11-13

[41] Ibrahim H Al-H 2012, Sept. Fouling in heat exchangers [Online] Available: http://dx.doi.org/10.5772/46462

[42] Bott T R 1981 The fouling of heat exchangers DSIR, Wellington (New Zealand)

[43] Troup D H, Richardson J A 1978 Scale nucleation on a heat transfer surface and its prevention Chemical Engineering Communications vol 2 pp 167-180

[44] Mueller-Steinhagen H M 1993 Fouling of heat transfer surfaces VDI Heat Atlas, English Edition, VDI- Verlag GmbH pp OC1-OC22

[45] Rautenbach R, Habbe R 1991 Seeding technique for zero-discharge processes, adaption to electrodialysis Desalination vol 84 pp 153-161

[46] 2014 Effective antiscale techniques, Plumbing, Heating, Air Conditioning 4 pp 62-65

[47] Parkinson G, Price W 1984 Getting the most out of cooling water Chemical Engineering pp 22-25

[48] Hasson D, Bramson D 1985 Effectiveness of magnetic water treatment in suppressing calcium carbonate scale deposition Industrial Engineering Chemistry: Process Design and Development vol 24 pp 588-592

[49] Ushakov G V 2006 Antiscale devices for protecting recycling water supply systems from hardness salt deposits Bulletin of Kuzbass State Technical University (Kemerovo) 6 pp 124-127

[50] Zverev V S, Akhmedzhanov R A 2009 Improving the effectiveness of the ultrasonic method for protecting heat transfer surfaces from scale Energy Saving and Water Treatment 1(57) pp 39-40

Acknowledgment
The authors are very grateful to Natalia Luneva, Natalia Evdokimova for their support and help in making this work possible.