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Some technological aspects of cleaning pipes of heat exchangers from solid scale deposits

This article discusses possible solutions to one of the problems associated with the low efficiency of existing thermal power plants. These factors are due to both the depreciation of equipment and the lack of any effective technologies for intensifying heat and mass transfer processes. The relevance of research topics is also confirmed by the fact that at the state level it is proposed to legally oblige the subjects of the heat and power industry to carry out preventive measures aimed at optimizing existing enterprises. The description of the reasons for the occurrence of scale deposits that appear in the in-line cavities is given. Due to the fact that the thermal conductivity of solid deposits is much less than the thermal conductivity of the metals from which the heat exchanger tubes are made, they significantly reduce the intensity of the processes and the intensity of heat transfer. Solid deposits lead to a decrease in the coolant flow rate, an increase in fuel consumption and a violation of the technological mode of operation of the entire heat exchange unit. The authors analyzed various technological aspects of various methods for cleaning heat exchanger tubes from solid scale deposits, on the basis of which the advantages of the electrohydraulic treatment method are substantiated. A schematic diagram of the device is given and a brief description of the method of cleaning the pipes of heat exchangers from solid scale deposits is given using electro-hydro-pulse action. The results of the application of this technology for cleaning heat exchange pipes at specific heat and power enterprises are shown, which confirm its advantages over other cleaning methods, both in terms of processing time and energy costs. The influence of the degree of purification of heat exchange pipes from solid deposits on the thermophysical parameters and efficiency of the heat exchanger is considered.

Keywords: heat exchanger, hard scale deposits, pipe cleaning, electro-hydro-impulse treatment, heat exchange efficiency.

Introduction

The energy-saving use of heat and power resources, the creation of new efficient ones, as well as the improvement of existing technical devices, is an important problem of scientific and technological progress. Heat exchangers are used to implement various thermal processes of heating, cooling, boiling, condensation and more complex physical processes — evaporation, absorption, heat transfer, etc. Heat exchangers are widely used in steam generators of nuclear power plants, gas-pipe installations and technological devices of chemical production, air conditioning systems, refrigeration and transport installations, etc. [1-5].

The development of energy intensity and production volumes requires an increase in the size of heat exchangers, which necessitates the search for ways to save fuel, materials and labor costs. According to JSC KOREM company, our “Kazakhstan's thermal power industry operates with a low efficiency [2, 6, 7]. Moreover, the Ministry of Energy has developed a Law obliging the subjects of the heat and power industry to carry out preventive measures aimed at optimizing existing facilities. The new legislation should ensure the technological renewal of the industry, the possibility of providing reliable, high-quality services to consumers, the reduction of specific and absolute levels of emissions, etc. The adoption of such measures at the state level is due to many technical and economic problems of the thermal power industry, such as a high degree of wear and tear of the main equipment — the national average wear of heating networks is 59 %; low thermal efficiency of existing equipment, high losses of thermal energy in thermal networks, etc. Among them, the problem of “lack of effective organization and planning of repair work to maintain and restore the main and auxiliary equipment of CHPPs, boiler houses and heating networks” is highlighted separately. In the proposed article, the authors consider some aspects of the technology, the application of which can determine possible ways to solve one of the most urgent problems of the domestic thermal power industry.

Problem statement and research method

It is known that the heat transfer largely depends on the cleanliness degree of working surfaces, because the presence of even a thin deposit of in-line deposits sharply worsens the process of heat transfer. Scale deposits have low thermal conductivity; they reduce heat transfer, so the heating of heat exchangers with deposits takes a longer time and requires more energy. Walls of heat exchange tubes in the presence of scale are heated to a higher temperature, which leads to a reduction in their service life. Therefore, in recent years, much attention has been paid to the fight against the occurrence of unwanted deposits in pipes, which not only reduce the efficiency of the boiler, but also increase fuel consumption [8-11]. Classical methods of dealing with scale are associated with the removal of hardness salts from the feed water (their absorption by various ion exchangers) or the addition of chemicals, such as phosphates, to the water [12]. These methods are very expensive, and therefore they are used mainly on large heat exchange devices.

It should be noted that at some technological enterprises, heat exchangers and boilers use pipes made of expensive metals and their alloys, such as brass, copper, LAMsh, etc., which are difficult to clean. Such pipes simply have to be cut and removed along with deposits. This is very costly and time consuming due to the need to stop the operation of the entire heat exchanger. The need to develop and implement an effective method for cleaning heat exchange pipes, which quickly removes solid deposits without deformation and rupture of the metal walls of the pipes directly, is an urgent task not only in Kazakhstan, but also in many CIS countries and far abroad.

Practice shows that the cleaning of heat exchange surfaces from solid deposits using electro-hydropulse (EHP) action is the most effective and environmentally friendly method [13]. In addition to cleaning heat exchange tubes, EHP technology is widely used in a wide variety of production processes and industries, for water disinfection, for crushing and grinding mineral ores, for breaking rocks, for demulsifying liquids, for cleaning oil and phosphorus deposits and others [14-18]. At the same time, the physical phenomena accompanying the processes of interaction between pressure shock waves and macroscopic structures in heterogeneous liquids have not been fully studied. This is due to their complexity and diversity, as well as the impossibility of preliminary calculation of the parameters of the EHP impact, which depend in each particular case on many factors. In this regard, the authors studied some technological aspects of cleaning the heat exchanger tubes from solid deposits using EHP action to determine the most optimal parameters and modes of this method and its effect on the efficiency of the heat exchanger.

The process of formation of scale deposits depends on both the temperature regime of the heat carrier and the water treatment of the source water. As a rule, industrial water, which always contains various impurities in the form of gas bubbles or dispersed solid particles, is used as a high-quality heat carrier at enterprises, technological installations of the chemical, oil and gas industries. Due to the presence of impurities of various salts in the process water in the form of fine-grained particles or dissolved substances, scale and solid deposits form in the heat exchangers during operation [10, 11].

Various impurities contained in water are divided into suspended and dissolved. Suspended substances consist of sand, clay, particles of organic and mineral origin and are removed from the water by clarification in mechanical filters. Of the dissolved salts in the water, magnesium chloride Mg Cl_2, sodium Na Cl, calcium Ca Cl_2, calcium sulfate Ca SO_4 and magnesium Mg SO4, carbonate and bicarbonate salts of calcium or magnesium Ca SO_3, Mg SO_3, Ca $(HCO_3)_2$, Mg $(HCO_3)_2$, as well as compounds of iron, aluminum, silicon [8, 10]. Calcium and magnesium salts have the greatest scale-forming ability. Scale deposits consist of a mixture of various chemical elements, the composition and structure of which also depends on the temperature regime of the coolant.

Numerous boilers, water heaters and other heat exchange devices of small and medium capacity, as a rule, use network water without special treatment. As a result, there is a rapid formation of scale deposits on the walls of heat exchangers. This is confirmed by the results of the analysis of the composition and structure of hard scale deposits formed on the inner surface of the pipes of heat exchangers of a number of operating thermal power facilities. As part of the research, the condition of the pipes of such heat exchangers as boilers and condensers of heat power plant HPP-3 in Karaganda city, the bakery boiler unit E-1/9-1 of Saran city, and others were studied.

The efficiency of cleaning heat exchangers from solid deposits can be ensured by a method based on the well-known electrohydraulic effect (EHE) by Yutkin L. This has been repeatedly confirmed experimentally, both by testing the EHP technology in laboratory conditions and directly by the results of cleaning various heat exchange pipes at operating industrial facilities [13-19].

Let's consider some technological aspects of cleaning the internal surfaces of heat exchanger tubes from solid scale deposits using EHP technology. Under EHP action, the destruction source of solid deposits is powerful impulse pressures at the front of shock waves, which are formed during a high-voltage electric discharge in water. It has been established that, first of all, thicker deposits are destroyed, and for the destruction of thin-layer deposits, it is required to increase the supplied discharge energy. In addition to the fact that this causes additional energy costs and can lead to unwanted ruptures of the pipe wall. Electric discharges are carried out near the cylindrical wall of the pipe. Therefore, it is necessary to take into account multiple reflections of pressure waves, which can enhance the effect of the EHP action, and under certain conditions, and vice versa, reduce it. It is difficult to determine in advance the pressure value at the shock wave front due to cavitation effects, phase changes in the working fluid, reaction of scale deposits, etc. that occur during EHP treatment.

To solve this problem, a team of authors proposed a method for removing solid deposits of various thicknesses that form on the inner surface of pipes, which can be implemented without an additional increase in the electrical parameters of the discharge [11, 17, 18]. According to the idea of the authors, a cable-electrode is inserted into the cavity of the cleaned pipe, which is installed in a cone-shaped nozzle made of durable material. Figure 1 shows a scheme for cleaning the surfaces of heat exchangers from solid scale deposits.

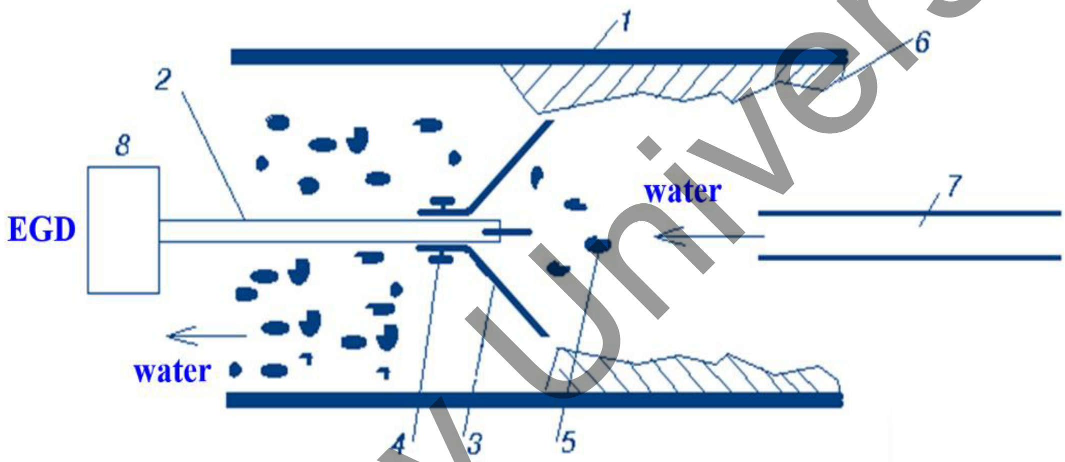

Figure 1. Scheme of the electro-hydro-pulse cleaning method:
1 — wall of the pipe being cleaned, 2 — cable-electrode, 3 — cone-shaped device, 4 — fastening, 5 — destroyed deposits, 6 — scale layer being cleaned, 7 — technical water, 8 — electro-hydraulic device (EGD).

The cone-shaped nozzle is made of steel (1.0÷1.5) mm thick. The outer diameter of the cone is smaller than the inner diameter of the heat exchanger tube being cleaned. During EHE, the shock wave propagates isotropically, in all directions, and the cone-shaped nozzle orients its movement along a certain solid angle, and therefore allows increasing the value of the wave pressure along the pipe axis. This phenomenon is associated with the cumulating effect, which provides an increase in the pressure of the shock wave in a certain direction, and, consequently, the effect of energy concentration.

The greatest increase in the pulse pressure amplitude was obtained when using a nozzle with a taper angle $\alpha=30^0$. The shock wave enhanced by the cumulative effect contributes to faster destruction and flaking of hard and superhard deposits located on the inner surface of the pipe. The periodic action of a powerful shock wave on the treated surface contributes to the destruction of solid deposits, thereby intensifying the process of cleaning the internal cavity of the heat exchanger tube. Destroyed and exfoliated sediment particles are carried away from the working area by the fluid flow. Let us consider examples of the successful application of the developed technology for cleaning pipes and tube bundles of peak boilers of thermal power plants, E1/9 steam boilers, etc.

As a result of the cleaning work using the EHP treatment, the heat exchange tubes are completely cleaned. Along with the cleaning of pipes the pressure testing of pipes and tube bundles was also carried out, and their suitability for further operation is determined.

Results and discussion

Treatment of brass pipes using electro-hydro impulse treatment.

Figures 2 and 3 are photographs of pipes sections of the heat exchangers of various diameters d with hard scale deposits. The solid scale deposits into pipes formed from CHPP-3 (Karaganda city) after operation during the season (about 6 months). It can be seen that inner surfaces of the pipes are completely cleaned after electrohydraulic treatment (Fig. 3b). The metal walls are not deformed, which allows them to be used in the heat exchanger in the future along with new ones.

a *b*

Figure 2. Samples of heat exchange pipes sections from CHPP-3 after operation during the heating season: a) — boiler pipe, d=19mm; b) — condenser pipe, d=28mm

a b

Figure 3. Samples of condenser pipes sections from CHPP-3, d = 24 mm
a) before processing; b) — completely cleared using the EHI effects.

The significance and practical importance of this technology is that the use of EHP- processing allows manufacturing enterprises to continue working in a short time with improved indicators of energy efficiency and economic profitability of equipment. As a result of the work carried out on the cleaning of heat exchange pipes, a methodology for its application was developed, equipment was created, which was tested and implemented at a number of thermal power facilities.

Treatment of steel pipes of the boiler unit E1/9 using electro-hydro pulse treatment.

The studied steam generator E1/9 worked for 9 months without stopping. Boiler plants of the plant provide production processes with saturated steam with humidity up to 30 % and at the same time cover all technological and heating loads. According to the passport data, the productivity of the E1/9 solid fuel steam generator should be 103 kg of steam per hour. In the E1/9 steam generator, the upper and lower drums are strictly located on the same vertical axis and are interconnected by tube bundles forming convective heating surfaces. Seamless pipes made of grade 10 steel are used. The pipe diameter is 51 mm and the wall thickness is 2.5 mm (Fig. 4).

It can be seen that some pipes after seasonal operation are almost completely filled (“clogged”) with solid deposits. These solid deposits are characterized by a denser, homogeneous, almost stone structure (Fig. 4a). Previously, pipes with such deposits were processed first using chemical reagents, then cleaned using a mechanical cutter. But this method does not allow to remove the formed solid scale deposits, as a result of which the uncleaned pipes used during one season were replaced by new ones. Examination of fragments of spent pipes showed that in almost 70 % of the pipes of the convective bundle, the solid scale thickness reaches about 13-15 m (Fig. 4b). When checking the condition of the equipment, burnt pipes were also found, inside which the scale hardened like a stone.

a b

Figure 4. Samples of boiler pipes before and after cleaning using EHP — treatment:
with hard deposits before processing; b) partially cleaned after processing, d = 51 mm

As part of the experiments, the dependence of the scale mass on the treatment time and the change in the thermal parameters of the E1/9 boiler as a result of cleaning using the EHP technology were revealed. Within 5 hours, with the help of EGI technology, 3 rows of 11 convective pipes, 1.1 m to 1.8 m long, were cleaned. A total of 48 m of convective pipes were processed. The total mass of hard scales after EHP treatment was determined [17, 19]. After draining the water from the lower drum, scale deposits were weighed. The total weight of scale deposits from 33 pipes was 83 kg, which is 1.8 kg on average per meter of pipe. The maximum fragment size was 37 98 mm; the appearance and dimensions of some broken and removed scale deposits are shown in Figure 4b.

About influence of EHP pipe treatment on heat exchanger efficiency.

In the course of activities during the EHP treatment of the internal cavities of pipes for cleaning from solid scale deposits, a change in thermophysical characteristics was studied. An analysis of the parameters of the considered steam generator E1/9 after continuous operation for 9 months showed that the heat removal decreased to 47 %, while the consumption of solid fuel increased by 1.75 times. Data on the dependence of the heat transfer of a pipe on the thickness of deposits, which are determined for brass pipes of boilers with a diameter of 18.8 mm, are obtained (without taking into account the contamination of the outer surface of the pipes).

The appearance of deposits with a thickness of δ = 0.5 mm reduces the heat transfer coefficient by 23 %. A further increase in the thickness of the existing scale significantly disrupts the technological mode of operation of the entire heat exchange unit. The flow rate of the coolant is reduced, which reduces the performance of the heat exchanger.

For example, calculations for the E1/9-1 boiler showed that a scale layer of 1 mm thick entails an increase in fuel consumption by 2.5 %, with a thickness of 4 mm — by 7.5 %, which in practice leads to an excess consumption of fuel oil by 770 kg/ day.

The thermal conductivity of scale is tens, often hundreds, times less than the thermal conductivity of the metals from which the heat exchanger tubes are made. The carried out changes showed that even with the appearance of deposits with a thickness of δ = 0.5 mm on the inner surface of the pipe, the heat exchange unit efficiency — η, % decreases (Fig.5). With an increase in scale thickness up to 7 mm on the heat transfer surface of a brass pipe (d=28 mm), the liquid flow through the pipe decreases by 1.5 times, which leads to a 2-times decrease in the efficiency of the installation. After the cleaning work, commissioning work was carried out, which showed that the efficiency of the boiler E1/9-1 η,% of the boiler reached 68 % at a nominal value of 75 %. The steam temperature reached 147ºC, at the norm of 170ºC.

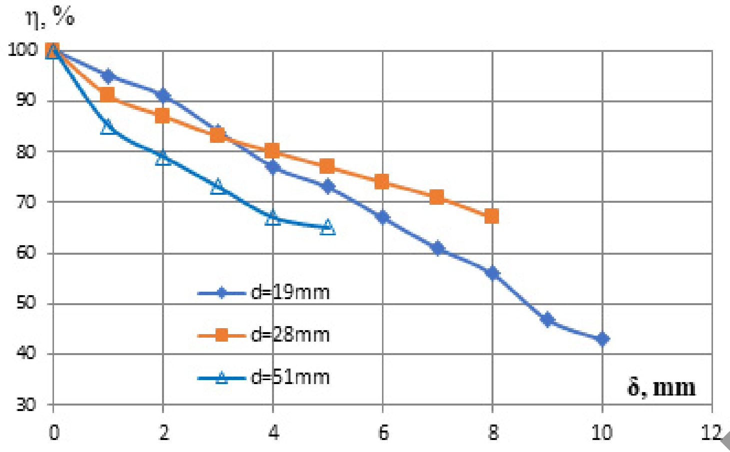

Figure 5. Dependence of the heat exchanger efficiency on the thickness of deposits.

The difference in efficiency values is due to the fact that some of the worn and burnt pipes were cut out and removed. These obtained results confirm that the removal of solid scale deposits in pipes contributes to the intensification of the heat transfer process and, accordingly, to the increase in the heat transfer efficiency of industrial heat exchangers.

Conclusion

Regular cleaning of pipes from solid scale deposits and the mandatory implementation of preventive measures against the occurrence of these deposits remain the most pressing problems of thermal power engineering so far. Obtained results have shown the undeniable advantages of cleaning the pipes of the heat exchanger and boiler units with the help of EHP technology. The speed of cleaning by this method is much higher than the productivity of the mechanical method with much lower power consumption. In general, the use of EHP impact for the destruction and removal of hard scale deposits from the internal cavities of pipes makes it possible to increase the efficiency of heat exchangers, and for heat and power enterprises to revise the cost items for major repairs and new purchases of materials. In the future, for a more effective solution to the problem of cleaning heat exchange pipes, it is necessary to comprehensively study the conditions for the formation of hard scale deposits, the mechanism and kinetics of their growth, structure and thermophysical properties, etc. This will allow not only to develop effective methods for removing scale deposits, but also to develop effective measures to prevent their formation.

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Жылу алмастырғыш құбырларды қатты қақтардан тазартудың кейбір технологиялық аспектілері

Мақалада жұмыс істеп тұрған жылу энергетикалық кәсіпорындардағы кондырғылардың тиімділігінің төмендеуін болдырмаудың бірден бір мәселелерін шешудің мүмкін жолдары талқыланған. Бұл факторлар жабдықтың тозуына да, жылу масса тасымалдау процестерін арттырудың тиімді технологияларының болмауына да байланысты болуы мүмкін. Зерттеу тақырыптарының өзектілігі негізінен жұмыс істеп тұрған кәсіпорындардағы жылу энергетикасы саласының субъектілерінде алдын алу шараларын жүргізумен қатар, мемлекеттік деңгейде және заң аясында оңтайландыруға бағытталған жұмыстарды міндеттеу көзделіп отыр. Себебі, жылу мен электр энергиясын өндіретін әрбір мекеме, мемлекетіміздегі стратегиялық нысан болып табылады. Сондықтан мақалада құбырішілік қабырғаларда пайда болатын шөгінділердің пайда болу себептерінің сипаттамасы келтірілген. Қатты шөгінділердің жылу өткізгіштігі жылу алмастырғыш құбырлар жасалған металдардың жылу өткізгіштігінен әлдеқайда төмен болғандықтан, жылу беру процестерінің қарқындылығын айтарлықтай азайтып жібереді. Ал сәйкесінше, қатты шөгінділердің пайда болуы салқындатқыштың шығынын азайтып, отын шығынын арттыруға және бүкіл жылу алмасу қондырғысының технологиялық режимін бұзуға әкеледі. Авторлар өз зерттеулерінде, жылу алмастырғыштар құбырларды қатты шөгінділерден тазартудың бірнеше әдістері мен әртүрлі технологиялық аспектілеріне талдаулар жүргізе отырып, электрогидравликалық өңдеу әдісін пайдаланудың артықшылықтарына басымдық берген. Мақалада құрылғының принципиалдық сұлбасы ұсынылып, жылу алмастырғыш құбырларын электро-гидро-импульстік әсерді пайдаланып, қатты қақтардан тазалау әдісіне қысқаша сипаттама берген. Сонымен қатар, жылу алмасу құбырларын тазартудың осы технологиясын нақты жылу энергетикалық кәсіпорындарда қолдану нәтижелері көрсетілген. Ал өңдеу уақыты бойынша да, энергия шығындары бойынша да тазалаудың басқа жолдарымен салыстырғанда, ұсынылған әдістің артықшылықтарын көруге болады. Зерттеулерде, жылу алмасу құбырларын қатты шөгінділерден тазарту дәрежесінің жылу-физикалық параметрлері мен жылу алмастырғыштың тиімділігіне әсері де қарастырылған.

Кілт сөздер: жылу алмастырғыш, қатты қақтар, шөгінділер, құбырларды тазарту, электр-гидроимпульсті өңдеу, жылу алмасу тиімділігі.

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Некоторые технологические аспекты очистки труб теплообменников от твердых накипных отложений

В статье обсуждены возможные пути решения одной из проблем, связанных с низкой эффективностью действующих теплоэнергетических предприятий. Эти факторы обусловлены как изношенностью оборудования, так и отсутствием каких-либо эффективных технологий для интенсификации процессов тепломассопереноса. Актуальность тематики исследований подтверждается также и тем, что на государственном уровне предлагается законодательно обязать субъекты теплоэнергетической отрасли проводить профилактические мероприятия, направленные на оптимизацию действующих предприятий. Приведено описание причин возникновения накипных отложений, которые появляются во внутритрубных полостях. Вследствие того, что теплопроводность твердых отложений намного меньше теплопроводности металлов, из которых изготовлены трубы теплообменников, они существенно снижают интенсивность процессов, интенсивность теплоотдачи. Наличие твердых отложений приводит к уменьшению расхода теплоносителя, увеличению расхода топлива и нарушению технологического режима работы всей теплообменной установки. Авторами проведен анализ различных технологических аспектов различных методов очистки труб теплообменников от твердых накипных отложений, на основе которого обоснованы преимущества метода электрогидравлической обработки. Приведена принципиальная схема устройства, и дано краткое описание метода очистки труб теплообменников от твердых накипных отложений с помощью электрогидроимпульсного воздействия. Показаны результаты применения данной технологии очистки теплообменных труб на конкретных теплоэнергетических предприятиях, которые подтверждают ее преимущества по сравнению с другими методами очистки как по времени обработки, так и по энергетическим затратам. Рассмотрено также влияние степени очистки теплообменных труб от твердых отложений на теплофизические параметры и эффективность теплообменника.

Ключевые слова: теплообменник, твердые накипные отложения, очистка труб, электрогидроимпульсная обработка, эффективность теплообмена.

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