Andrzej ADAMKIEWICZ
Maritime University of Szczecin, Poland
Faculty of Mechanical Engineering,
Department of Condition Monitoring & Maintenance of Machinery
a.adamkiewicz@am.szczecin.pl
Bogdan POJAWA
Polish Naval Academy, Poland
Faculty of Mechanical and Electrical Engineering,
Institute of Construction and Operation of Ship
b.pojawa@amw.gdynia.pl

OPERATIONAL DIAGNOSTICS OF DAMAGE TO HEAT EXCHANGE SURFACES OF HIGH-PRESSURE RECUPERATION EXCHANGERS IN A BLOCK OF A HEAT AND POWER GENERATING PLANT

Key words

Degradation of heat exchange surfaces, recuperation heater, heating block, heat and power generating plant.

Abstract

This paper presents the results of research into high-pressure recuperation heaters used in BC -50 heating blocks of a chosen heat and power generating plant. During the operational process of heat exchangers in some characteristic locations of heat equipment, intensive repetitive degradation of heat exchange surfaces takes place that requires looking into its origins. This degradation led to the perforation of walls of tube packets in extreme cases. The aim of the

research was to identify the causes of the damage in order to eliminate them. The research relied on the measured operational parameters of the studied heat exchangers recorded in a passive experiment by a recording control system of a heating block.

Introduction

Obtaining the possibly highest power efficiency of heating blocks of heat and power generating plants is the result of bringing the realized thermal cycle near to the Carnot cycle by superheating the steam from the boiler and interstage (bleed steam from the turbine), recuperative heating of water feeding the steam boiler [12, 13, 16, 20], and applying co-generation [4, 5]. The basic way to obtain a highly effective power conversion in heating block operation includes maintaining all the machines and facilities of the block in the best technical condition [4, 6, 10, 12]. It is especially valid for heat exchangers that are the object of intensive degradation processes. Occurrence of faults, and as their result damage to elements of heat exchangers, may be the cause of the decrease of the power efficiency of the whole block and even the necessity to switch it off completely [4, 6, 12].

The most important heat exchangers of the heating block are, among others, the high-pressure recuperation heaters of water feeding the steam boiler. These heaters operate in difficult and changeable conditions of thermal-mechanical load [12, 21]. Their main operational drawback leads to evolutionary and unavoidable heat exchanger faults resulting in degradation of the technical condition of heat exchange surfaces from the effect of corrosion, erosion, and contamination with deposits [1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 14, 15, 17, 18]. As a result of excessive deposits (“boiler scale”), the conditions of heat exchange deteriorate, the temperature of tube walls increases, and they become overheated and deformed which accelerates the process of destruction – corrosion and initiation of cracks [4, 6, 8, 10]. Simultaneous occurrence of corrosion and erosion processes leads to material loss, cavities, cracks, and in extreme cases, even the perforation of tube walls.

While servicing the studied heat exchangers, a number of surface faults were observed. These included perforations in the tubes in the middle section of the pack (Fig. 1), which is under the direct influence of a steam flow rate from the unregulated turbine steam extraction.

A repetitive operational fault has become a daunting technical and servicing problem requiring locating its origins and preventing its further development. The above issue spurred this study.

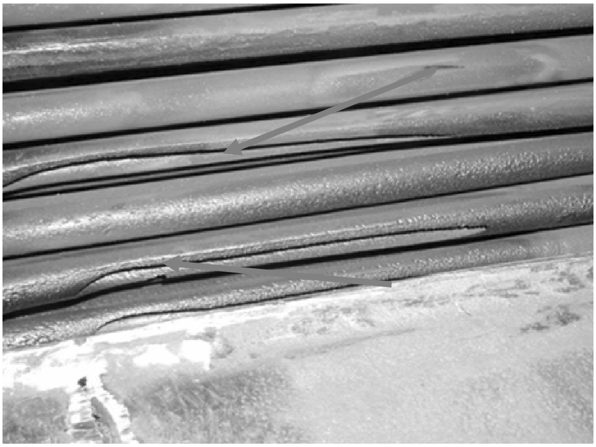

Fig. 1. An image of the perforations of tubes of a heater located opposite the piping feeding steam to the heat exchanger [12]

1. Study Object Identification

A heating block of the BC-50 type, operating in a heat and power generating plant functioning in a big urban area was the subject of the study. It comprised a steam boiler of the OP-230 type, a two-cylinder turbine of the 13UP-55 type, an alternator, and auxiliary equipment supporting generation, i.e. a belt conveyor, a coal pulveriser, heat exchangers, degassers, pumps, ventilators, and others [22]. A simplified diagram of a BC-50 heating block is shown in Fig. 2.

The main heat exchangers of the BC-50 heating block of a heat and power generating plant comprise three-zone surface recuperation heaters of the PWU–300/250 (HPR2) and PWU–250/210 (HPR1) types. These heaters are the pressure part of the heating of water feeding the block steam boiler. The heating medium is the superheated steam from the non-regulated steam bleeding part of the high-pressure part of the steam turbine and the condensate formed from this steam. Each of the heaters comprises of a proper heater and a condensate cooler. The proper heater has two zones of heat exchange: the zone where the superheated steam is cooled to dry saturated steam and the condensation zone. The heater comprises the following main parts: a water chamber with a pack of tubes, a steam chamber, and a condensate cooler. In the heaters, there is a one-stream, counter-current flow of the working media [12, 21]. Figure 3 shows a diagram with the location of control points and the identification of operational parameters of the studied heat exchangers in compliance with the accepted flow model with concentrated parameters.

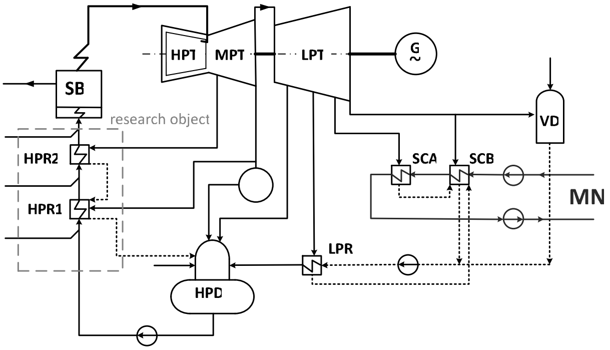

Fig. 2. A simplified diagram of a BC-50 heating block [22].

SB – steam boiler, HPT – high-pressure turbine, MPT – medium-pressure turbine, LPT – low-pressure turbine, G – generator, VD – vacuum degasser, SCA, SCB – steam condensers, LPR – low-pressure recuperation exchanger, HPD – high-pressure degasser, HPR1, HPR2 – high-pressure recuperation exchangers, MN – municipal heat distribution network

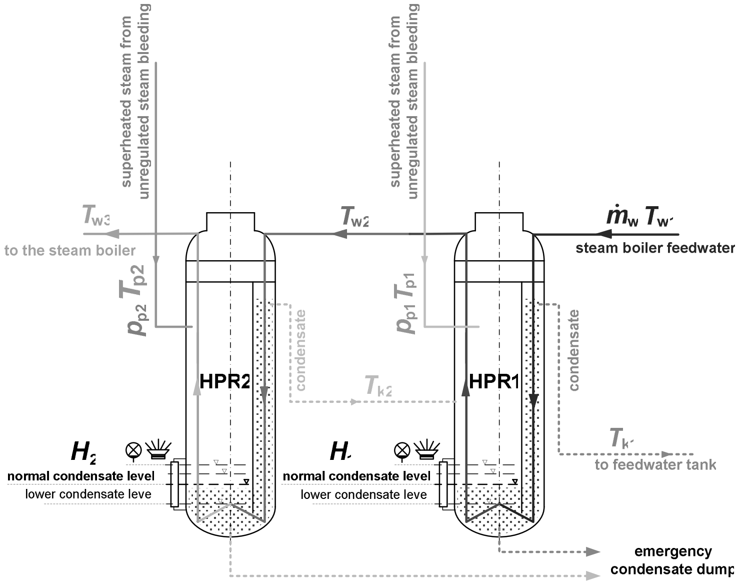

Fig. 3. A diagram of high-pressure recuperation heaters of the HPR1 and HPR2 types in BC-50 heating block [21].

T_{w1} – water temperature at the inlet to HPR1, T_{w2} – water temperature at the outlet from HPR1 (and at the inlet to HPR2), T_{w3} – water temperature at the outlet from HPR2, p_{p1} – steam pressure at the inlet to HPR1, p_{p2} – steam pressure at the inlet to HPR2, T_{p1} – steam temperature at the inlet to HPR1, T_{p2} – steam temperature at the inlet to HPR2, H_1 – level of condensate in WP1, H_2 – level of condensate in HPR2, T_{k2} – condensate temperature at the outlet from HPR2 (at the inlet to HPR1), T_{k1} – condensate temperature at the outlet from HPR1, $\dot{m}_w$ – steam boiler feedwater flow rate

2. Methodology of studies

The character of faults and their location indicate that occurring perforations of tubes were the result of intensive erosion processes generated by the stream of inflowing steam. Therefore, for this research, it has been decided to carry out a detailed analysis of parameters and the states of the functions of steam and operational parameters of heat exchangers in a possibly wide range of load.

The research relied on measurement results from the database of the considered heating block registered by its control system. This system is designed to control the condition and operation of heaters, and the readings are used by the system of control and safety of the block. Additionally, the control results are recorded on–line with the 0.1 Hz frequency and stored in the database [22]. Using the control-recording system, the following were measured:

- Temperatures, pressures and flows of working media in characteristic planes of the control installation;
- Rotational speed, voltage and electrical power at current generator terminals;
- Composition and mass flow of the exhaust, with the accuracy of equipment and detectors in the following classes of accuracy:
  - Media flow using measurement reducers and transformers of pressure difference of class 0.1;
  - Pressures using pressure transformers of class 0.1;
  - Temperatures using resistance thermoelements Pt-1000 of class A and (NiCr-NiAl) thermoelements of class 1; and,
  - Electrical power at generator terminals with a microprocessor power meter WMM-04 throughout current and voltage transformers of class 0.2 ensured by a periodical calibration of measurement tracks.

Limiting errors of the used measurement equipment were as follows:

- Pressure and pressure difference transformers ±0.1% of the range;
- Type K thermoelements of class 1 form ±1.5°C with temperatures up to 375°C, up to ±0,4% at higher temperatures;
- Resistance thermoelements Pt-1000 of class A – ±(0.15 + 0.002 × temperature) °C; and,
- Power meter WMM-04 up to ±0.2% of the range.

3. Handling and analysis of research results

From among the recorded physical values, only those characterizing the operation of heaters HPR1 and HPR2 were chosen. Based on statistical analysis of measurement results in stabilized states, their mean values were determined in a one-hour period that formed a base for precise analysis.

It has been stated that parameters maintain their values in compliance with those in the technical manual of the heating block (close to designer values) in the whole range of its load. The only parameter that often and significantly differed from designed values was the level of condensate, especially in the HPR1 heater, which is shown in Fig. 4. This level was often below the lower limit level of condensate, which suggested that steam could be blown through in the heater. Therefore, for further research, such measurement results were chosen which were carried out at a heater condensate level below the normal operational one for different loads of the heating block. The normal level of condensate is in compliance with the designed values for the heater and is denoted as zero. It was assumed that, at this level of condensate, the heat of steam condensation and heat obtained from cooling the condensate are fully utilized according to the following relationship:

$$\dot{Q}_W = \dot{Q}_P + \dot{Q}_S + \dot{Q}_K \tag{1}$$

where

$\dot{Q}_W$ – total heat flow rate transferred to the steam boiler feedwater,

$\dot{Q}_P$ – heat flow rate of superheated steam,

$\dot{Q}_S$ – heat flow rate of steam condensation,

$\dot{Q}_K$ – heat flow rate contained in the condensate.

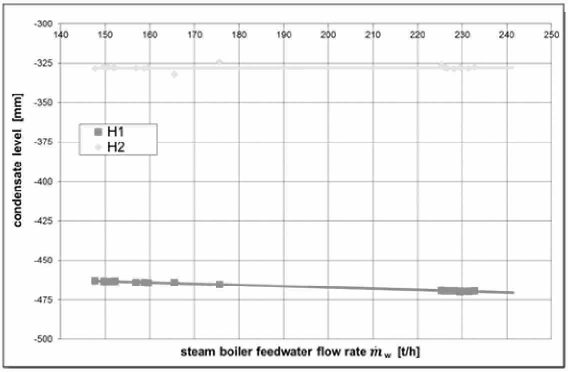

Fig. 4. A relationship between H_1 and H_2 condensate and the steam boiler feedwater flow rate $\dot{m}_w$

Figure 4 shows that, together with the growth of the mass flow rate of the water feeding the steam boiler (load of the heating block), the level of condensate in the HPR1 heater decreases, until it is below its acceptable value (see Fig. 3). On the other hand, the level of condensate in the HPR2 heater remains constant regardless of the block load, and it does not go below its acceptable value. Based on the above, it can be concluded that, during the operation of the studied heaters, states of faulty non-designed operation occur especially in the range of maximum loads of the heating block.

For operation ranges presented in Fig. 4, relationships of temperatures of steam, condensate, and water feeding the boiler versus the steam boiler feedwater flow rates (block load) were determined for further analysis. These relationships are presented in Figs. 5 and 6. While determining those relationships, the values of parameters equal to design values were taken into consideration. In order to make the figures easier to read, they only show the values of the studied parameters referring to the control points without the approximated ones.

The relationship presented in Fig. 5 indicates that, in the HPR1 heater, there is no respective relationship between steam, water, and condensate temperatures, especially for the maximum block load. The temperature of water feeding the boiler at the inlet to the HPR1 (T_{w1}) is lower (much lower than designed) than the temperature of the condensate T_{k2}. On the other hand, the temperature of the water feeding the boiler at the outlet from HPR1 (T_{w2}) is higher than the temperature of the condensate and saturated steam $T''_{p2,}$ which may support the previous assumption that steam blow through takes place in the HPR1 heater.

From the relationships shown in Fig. 6, it can be concluded that the temperatures of steam, water, and condensate characterizing the operation of the HPR2 heater remain in correct relationships with each other in compliance with the designed assumptions in the whole range of loads of the heating block. This includes the temperature of the water feeding the boiler at the outlet from the HPR2 (T_{w3}) being equal to the temperature of saturated steam T''_{p2}.

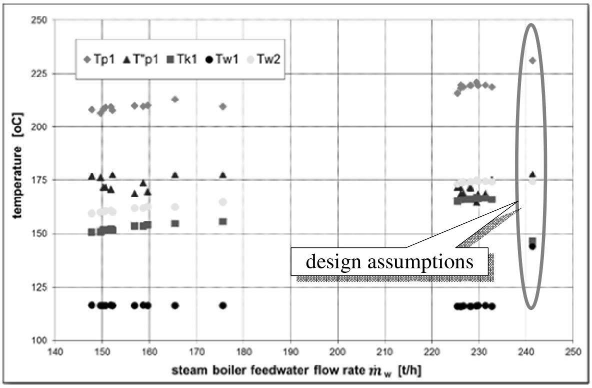

Fig. 5. A relationship of the temperatures of steam, water, and condensate characterizing the operation of the HPR1 heater versus the steam boiler feedwater flow rate $\dot{m}_w$ T''_{p1} – temperature of the dry saturated steam in the HPR1

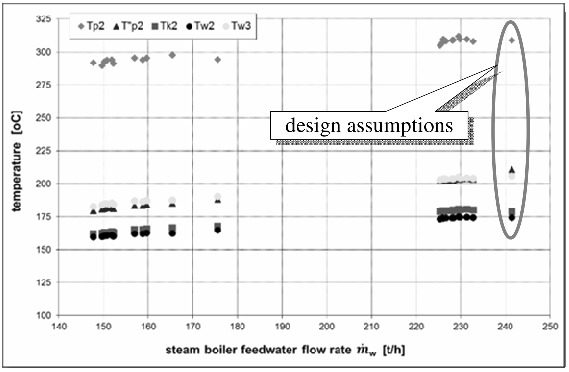

Fig. 6. A relationship of the temperatures of steam, water, and condensate characterizing the operation of the HPR2 heater versus the steam boiler feedwater flow rate $\dot{m}_w$
T''_{p2} – temperature of the dry saturated steam in the HPR2

These conclusions pointed to the need of determining a relationship of the enthalpies of superheated and saturated steam at the inlet to the studied heaters versus the load of the block and comparing them with the results of calculations on designed values, which is shown in Fig 7. The enthalpies were determined based on the values of temperatures shown in Figs. 5 and 6 and the pressures of steam measured at the inlet to the studied heaters.

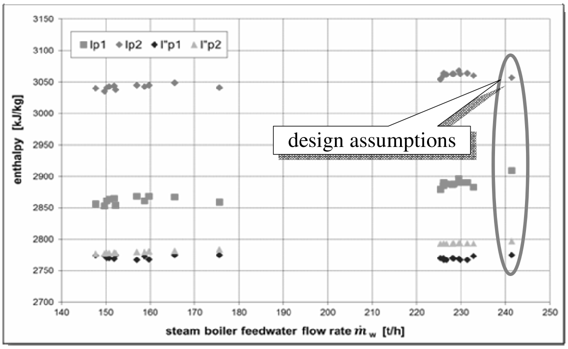

Fig. 7. A relationship of superheated steam i_p and saturated steam i''_p at the inlet to the HPR1 heater (i_{p1}, i''_{p1}) and to the HPR2 heater (i_{p2}, i''_{p2}) versus the steam boiler feedwater flow rate $\dot{m}_w$

From the relationship shown in Fig. 7, it can be concluded that steam parameters at the inlet to both heaters for different loads of the heating block maintain similar values of enthalpy close to the designed values. It confirms the correct way of controlling the load of the heating block ("quality").

Having the recorded values of temperature and assuming their respective values of mean specific heat of water, flows of heat delivered to the heaters, in order to heat the water feeding the boiler, were determined and compared with the designed values. A relationship between the determined heat flows and mass flow of the water feeding the boiler $\dot{m}_{\mathrm{w}}$ (block load) are presented in Fig. 8, which shows that, in the HPR2 heater, the heat flow delivered for heating the water feeding the boiler $\dot{Q}_{\mathrm{w2}}$ is proportional to the load of the heating block and its maximum value corresponds with the designed one ($\dot{m}_{\mathrm{w}}$ = 241.4 t/h, $\dot{Q}_{\mathrm{w2}}$ = 33.09 GJ/h).

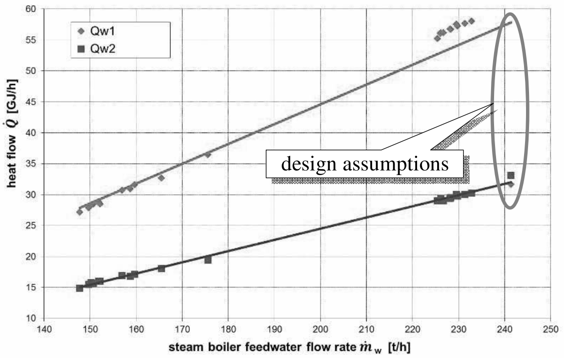

Fig. 8. A relationship of the heat flow rates delivered to heat the water supplying the steam boiler in the HPR1 heater ($\dot{Q}_{\mathrm{w1}}$) and the HPR2 heater ($\dot{Q}_{\mathrm{w2}}$) versus the steam boiler feedwater flow rate $\dot{m}_{\mathrm{w}}$

However, in the HPR1 heater, the heat flow delivered for heating the water feeding the boiler $\dot{Q}_{\mathrm{w1}}$ is almost twice as big as the heat flow determined for designed values ($\dot{m}_{\mathrm{w}}$ = 241.4 t/h, $\dot{Q}_{\mathrm{w1}}$= 31.66 GJ/h). The increased values of $\dot{Q}_{\mathrm{w1}}$ occur mainly for the range of loads of the heating block that is close to the maximum one. Taking into account that, for these loads, there is a low level of condensate (Fig. 4) and a low pressure of steam feeding the HPR1 heater, it can be assumed that a blow through of the steam took place in the HPR1 heater, and thus the part played by the heat of condensation in the whole process of heat exchange was smaller. The above should result in an increased steam flow at the inlet to the WP1 heater. To verify this assumption, mass flows and the speeds of steam feeding the HPR1 and HPR2 heaters were determined. These relationships are shown in Fig. 9 and Fig. 10.

Figure 9 indicates that steam flows calculated from the designed values for the HPR1 and HPR2 heaters are close to each other. The determined steam flow for the HPR2 heater ($\dot{m}_{\mathrm{p2}}$) is proportional to the load change of the heating block with a maximum value corresponding to the designed assumptions. The determined steam flow for the HPR1 ($\dot{m}_{\mathrm{p1}}$) is proportional to the change of load of the heating block; however, it is almost twice as high as the steam flow derived from designed values. It supports the earlier assumptions on the existence of a blow through of steam at low levels of condensate.

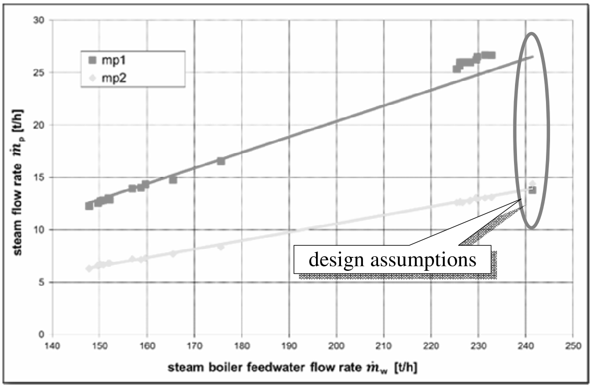

Fig. 9. A relationship of the steam mass flow rates at the inlet to the HPR1 heater ($\dot{m}_{\mathrm{p1}}$) and to the HPR2 heater ($\dot{m}_{\mathrm{p2}}$) versus the steam boiler feedwater flow rate $\dot{m}_{\mathrm{w}}$

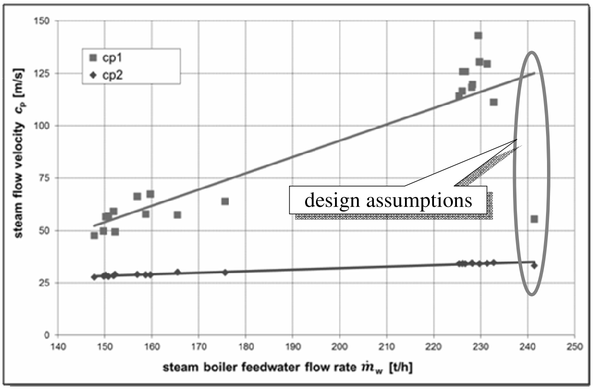

Fig. 10. A relationship of steam flow velocities at the inlet to the HPR1 heater (c_{p1}) and to the HPR2 heater (c_{p2}) versus the steam boiler feedwater flow rate $\dot{m}_{\mathrm{w}}$

The relationships shown in Fig. 10 suggest that the determined speed of steam flow at the inlet to the HPR2 heater (c_{p2}) for a defined steam flow and specific volume corresponding to T_{p2} and p_{p2} remains approximately constant in the whole range of the load change of the heating block and corresponds with designed values. However, the determined speed of steam flow at the inlet to the HPR1 heater (c_{p1}) for a defined steam flow and specific volume T_{p1} and p_{p1} is proportional to the load change of the heating block and two times higher than the designed value. At the same time, there is a noticeable scatter of speed values due to the change of state parameters of the steam feeding the HPR1 heater.

Conclusion

The above discussion based on carried out research indicates the existence of the perforation of tube walls in the studied heat exchangers. They could be due to intensive degradation processes of the erosive-corrosive nature caused by the inflowing steam. Intensification of the erosive process was caused by the blow through of the steam, which was the result of a low level of condensate and was accompanied by the increase of speed and flow of the steam. The correctness of this conclusion is confirmed by the location of tube wall perforations, which occur opposite the pipe supplying the steam to the heat exchanger. The intensification of the erosive process could have also been influenced by the quality of water feeding the steam boiler. Therefore, during the operation of a heating block, the quality of water should be systematically controlled.

The existing increase in the flow of steam feeding the HPR1 heater caused by the steam blow through also influenced the decrease of steam flow on the turbine. With a constant temperature of water feeding the boiler, the amount of electrical energy generated by the heating block decreased. As a consequence, it led to lowering power effectiveness of the heating block and it increased its running costs.

Therefore, operation of a heat exchanger should take place at a carefully maintained level of condensate in the heaters. In order to avoid emergency switch-off of the block due to an increased level of condensate, there should be an automatic system allowing a fast "dump" of condensate from the heaters. Heat exchange surfaces of the heaters of water feeding the boilers undergoing such changes should be systematically controlled with endoscopic methods.

References

1. Adamkiewicz A., Valishin A.: Discussion and studies of the properties of a cooling water additive preventing erosive wear of cooled surfaces of ship diesel engines. Eksploatacja i Niezawodność – Maintenance and Reliability 2014; 16 (4): 565–570.
2. Chen X., Xu R.Q., Shen Z.H., Lu J., Ni X.W.: Optical investigation of cavitation erosion by laser-induced bubble collapse. Optics and Laser Technology 2004: 36(3): 197–203.
3. Deku A., Kompella S.: Cavitation in Engine Cooling Fluid due to Piston-Cylinder Assembly Forces. Sweden: Department of Mechanical Engineering, Blekige Institiut of Technology, 2006; 68.
4. Dobosiewicz J.: Badania diagnostyczne urządzęń cieplno-mechanicznych w energetyce – część II. Kotły i rurociągi. Gamma, Warszawa 1999.
5. Flynn D. (eds.).: Thermal Power Plants -Simulation and Control. The Institution of Electrical Engineers, London 2000.

6. Hernas A., Dobrzański J.: Trwałość i niszczenie elementów kotłów i turbin parowych. Wydawnictwo Politechniki Śląskiej, Gliwice 2003.
7. Holfield R.: Cavitation erozion of cylinder lines and how to eliminate it. Pipelnie & Gas Journal, 1999; 226(3): 36.
8. Jankowski T., Głowacka M.: Uszkodzenia korozyjne wymienników ciepła za stali austenitycznej 18/8. Konferencja Dobór i eksploatacja Materiałów Inżynierskich. Gdańsk-Jurata 1997: 248–253.
9. Korzeniewski H. Przyczyny korozji lokalnej rurociągu uzdatniania wody. Problemy eksploatacji 2009; 1: 123–134.
10. Łabanowski J., Głowacka M.: Eksploatacyjne uszkodzenia stali austenitycznych w urządzeniach energetycznych. Przegląd Spawalnictwa 2010; 12: 3–9.
11. Pr. zb. (red. Darowicki K.). Procesy korozyjne. Wydawnictwo Politechniki Gdańskiej, Gdańsk 2008.
12. Pojawa B., Strumski P.: Ocena efektywności energetycznej podgrzewaczy regeneracyjnych wysokoprężnych bloku ciepłowniczego elektrociepłowni. Rynek Energii 2012; 6 (103): 27–33.
13. Pudlik W. Termodynamika. Wydawnictwo Politechniki Gdańskiej, Gdańsk 1998.
14. Steller J, (ed.). International Cavitation Erosion Test. Preliminary Report. Part I: Co-ordinator's Report, IMP PAN Rep., 1998; 17.
15. Sun Z., Kang X.Q., Wang X.H.: Experimental system of cavitation erosion with water-jet. Materials and Design 2005; 26(1): 59–63.
16. Szargut J.: Termodynamika. Wydawnictwo Naukowe PWN, Warszawa 1998.
17. Wenge G., Chenqing G., Kang Z., Fusan S.: Corelation of cavitation erozion resistance and mechanical properties of same engineering steel. Journal of Materials Science 2006; 41(7): 2151.
18. Wranglen G.: Podstawy korozji i ochrony metali. WNT, Warszawa 1975.
19. Yangzeng Z. Tianfu J. Mei Y. Wantang F. Structural changes after cavitation erosion for a Cr-Mn-N stainless steel. Wear 1997; 205: 28–31.
20. Yunus A., Cengel, Michael A.: Boles. Termodynamics fifth edition in SI units. McGraw–Hill Higher Education, New York 2006.
21. Dokumentacja techniczna podgrzewaczy PWU–300/250 i PWU–250/210.
22. Dokumentacja techniczna bloku ciepłowniczego BC-50.

Analiza przyczyn degradacji stanu technicznego powierzchni wymiany ciepła wysokoprężnych wymienników regeneracyjnych bloku elektrociepłowni

Słowa kluczowe

Degradacja powierzchni wymiany ciepła, podgrzewacz regeneracyjny, blok ciepłowniczy, elektrociepłownia.

Streszczenie

W artykule przedstawiono wyniki badań wysokoprężnych wymienników regeneracyjnych stosowanych w blokach ciepłowniczych BC–50 wybranej elektrociepłowni. W procesie eksploatacji wymienników ciepła występuje w charakterystycznych lokalizacjach aparatów cieplnych powtarzająca się, wymagająca rozpoznania genezy, intensywna degradacja stanu ich powierzchni wymiany ciepła. Degradacja ta w skrajnych przypadkach doprowadzała do perforacji ścianek pakietów rurowych. Przeprowadzone badania miały na celu zidentyfikowanie przyczyn powstawania tego typu uszkodzeń w celu ich wyeliminowania. W badaniach wykorzystano wyniki pomiarów parametrów pracy badanych wymienników ciepła zarejestrowane w eksperymencie biernym przez układ pomiarowo-rejestrujący bloku ciepłowniczego.