Biogas and Biomethane from Animal Waste for Electricity Production

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***Abstract*—The biogas or biomethane production process is becoming a great potential for the development of Polish agriculture and gives many benefits the environment i.e a reduction of methane emissions to the atmosphere or limitation of landfills. In the paper the current situation and perspective for the development of agricultural biogas plants in Poland is presented. Additionally, an analysis of the biogas and biomethane production potential from animal manure in Poland and Opolskie voivodship was presented. The calculation showed that both for the country and the voivodship the largest potential for electricity production was found for cattle manure (about 4 mln MWh) and cow manure (about 2 mln MWh).**

Keywords—biogas, biomethane, animal waste, energy, electricity production

I. Introduction

As part of the EU's climate and energy policy, it was decided to almost decarbonize the energy sector completely by 2050, and by 2030, targets were set based on reducing greenhouse gas emissions, increasing the share of renewable energy and improving energy efficiency.
One of the most important goals in EU's policy by 2030 is [1]:

- a reduction of at least 40% of greenhouse gas emissions (in relative to the 1990 level),
- increasing the share of energy from renewable sources to at least 32% total energy consumption,
- an increase of at least 32.5% in energy efficiency.

A significant element of the Polish energy development strategy until 2040 is, in addition to the development of large-scale energy units, also the development of distributed and civic energy (e.g., photovoltaic installations) and the development of the biogas and biomethane production sector [2].
Fig 1 shows the structure of energy production from renewable sources in Poland in 2019. The share of biogas in this energy structure is relatively low because it is 2.4%. For example, in Germany it is 16.5%, the Czech Republic 11.5% and 7.6% in Italy [3].

It is estimated that biogas production will be more and more common in recent years. Its production from agricultural waste and crops is a great opportunity for Polish agriculture.
Biogas is produced in the anaerobic fermentation process of biomass. Due to the way of obtaining it, biogas can be divided into: landfill biogas (waste fermentation in landfills), biogas from sewage sludge (fermentation of sewage sludge in municipality wastewater treatment plants), biogas of agricultural origin.

The production of biogas is an important option in managing the existing wastes, as this process applies organic matter, which is difficult in application by other methods. In addition, biogas plants can aid in the utilization of waste produced in a given area, as the waste can be used locally.

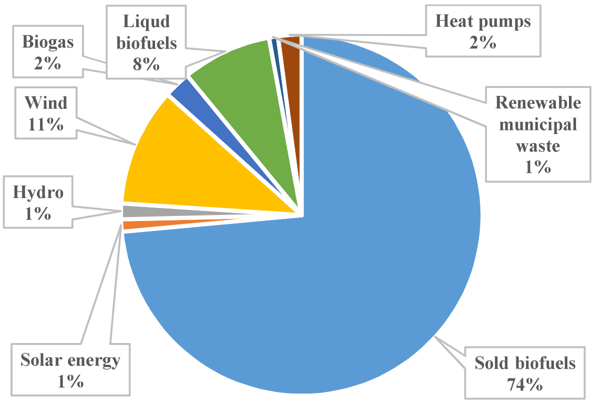

Fig. 1. The structure of energy production from renewable sources in Poland in 2019 [3].

The production of biogas is an important option in managing the existing wastes, as this process applies organic matter, which is difficult in application by other methods. In addition, biogas plants can aid in the utilization of waste produced in a given area, as the waste can be used locally.
The construction of biogas plants is individual and depends on various factors, mainly on the type of batch material.

For the biogas production in the agricultural biogas plants substrates are used in solid or liquid form and different factions, which can be separated from each other and different proportions to obtain assumed composition of biogas. Typical range of content of biogas is presented in Table I.

TABLE I. Composition of Biogas [2-8]

Parameters	Value, %
CH_4	40-70
CO_2	15–60
H_2O	2-7
N_2	2-5
O_2	0-2
H_2	< 1
NH_3	0-1
H_2S	0.005–2

Production of biogas can be carried out using different methods.
The most common criteria for the types of biogas production technologies include: the number of stages of the technological process, temperature, type of substrates and the content of dry matter in the substrate.
Biogas can be used in most applications designed for natural gas which can be used to produce heat and electricity.
Technical possibilities of biogas using include the following variants [9,10]:

- direct combustion of gas boilers,
- production of electricity in gas engines with power generator,
- cogeneration or trigeneration,
- the production of biomethane, which can be injected into the natural gas distribution networks, used in industrial processes or as a transport fuel.

We consider the so-called biofuel as biomethane 2nd generation, obtained from materials that do not compete with food in any way. These are primarily materials of origin wood, straw and other types of secondary biomass x agricultural production (in particular manure), also landfill gas from fermentation of municipal waste and biogas from sewage treatment sludge fermentation sewage.
In CHP plants the electrical efficiency can score up to 41% in bi- and trigeneration installations the efficiency of heat and electricity production can be higher than 60% [4].

The development of biogas production technologies and various possibilities of its use create large energy production possibilities, which are much higher than the current level.
The local and legal conditions have an impact on the development of biogas plants and influences for investment in biogas sector.

In the paper the current situation and perspective for the development of agricultural biogas plants in Poland is presented as well as it is estimated potential of the production of electricity from animal waste in local (based on Opole voivodship) and national scale.

II. Feedstock for Biogas Production

In Poland the potential expressed in terms of the volume of the material from agriculture is estimated at 5vbillion m^3 of biogas, whereas the potential in the side products from agriculture and waste from the agricultural and food production is estimated at 1.7 billion m^3 of biogas annually [11].
Feedstock for biogas production can be:

- Agricultural wastes:
  - ✓ Livestock manure,
  - ✓ Feeding stuff remains,
  - ✓ Energy crops,
  - ✓ Waste from plant cultivation,
  - ✓ Grass clippings and garden refuse,
  - ✓ Kitchen waste.

Industrial wastes:

- Waste from food industry:
  - ✓ fruit and vegetable processing,
  - ✓ dairy production,
  - ✓ bakeries and sugar production,
  - ✓ distillery and meat sector.

In Poland the most common types of waste applied in agricultural biogas plants are presented in Fig 2.

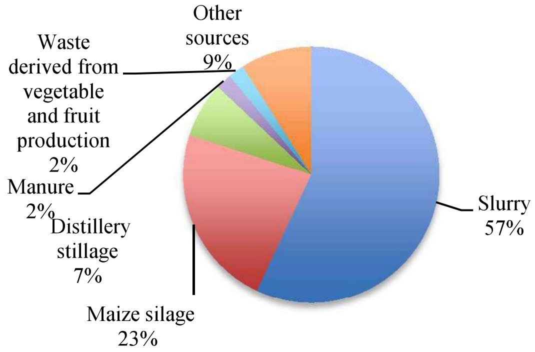

Fig. 2. Types of waste applied in agricultural biogas plants [11].

The wastes differ in the organic dry matter content, the rate of decomposition, and the amount of biogas produced. Table II summarizes the characteristics of various raw materials, taking into account the dry matter content, biogas efficiency and methane content in the obtained product.

TABLE II. Efficiency of Biogas from Various Materials [5,14]

Substrate	**Content, %**		**Theoretical biogas efficiency, dm^3**	**Content of methane, %**
	dry mass	organic dry mass	from 1 kg organic dry mass	-
Cow manure	8-11	75-82	200-500	50-55
Pig manure	4-7	75-87	300-700	50-70
Cow dung	20-26	68-78	270-450	55-60
Pig dung	20-25	75-80	270-450	55-60
Chicken litter	30-32	63-80	250-450	57-70

Efficiency of biogas production in the largely depends on the substrates used and the quantity of biogas resulting from the content of organic compounds in the substrates. In current practice, co-substrates are usually added to increase the organic content and thus achieve a higher gas yield [12].
All biogas substrates should be free of pathogens and, depending on the types of pathogens they are subjected to pasteurisation processes at 70 °C or sterilization at 130 ° C before the fermentation [13].
In agricultural biogas plants currently being implemented in Poland, the most common are installations using the process of co-fermentation of animal manure with agricultural by-products or energy crops.

III. Biogas Production In Poland

The register of biogas producers shows that for 2021 there are over 300 units in Poland. For comparison, in Germany, there are approx. 9.5 thousand. According to the Office for Energy Regulation data [15] in 2020 there were operated 116 agricultural biogas plants in Poland. It was 38.66 % of all facilities. As a comparison, in 2011 there were only 17 agricultural biogas plants.

The Installed Electric Capacity (IEC) increased in Poland from 31.91 MW in 2005 to 255.7 MW in 2020 (Fig. 3).

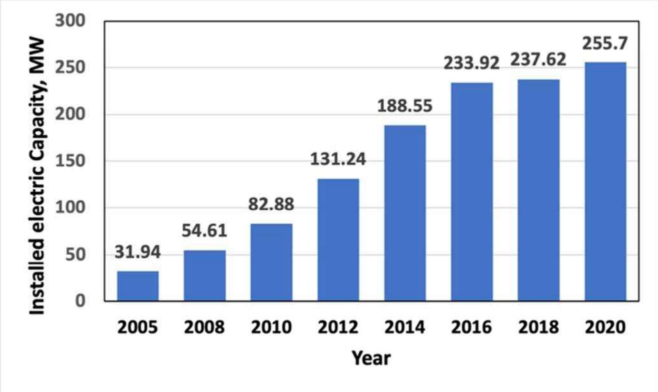

Fig. 3. Growth in Installed Electric Capacity in biogas sector in Poland [15].

The structure of Polish agricultural biogas plants is dominated by installations with a capacity in the range of 0.5 to 1.5 MW, (56% of all facilities) [15].

On the basis of the analysis of the particular types of biogas plants in Poland, we are able to identify the regions in which a given type of biogas plants is more common than others. Fig. 4 presents a map giving the location of the biogas plants in Poland.

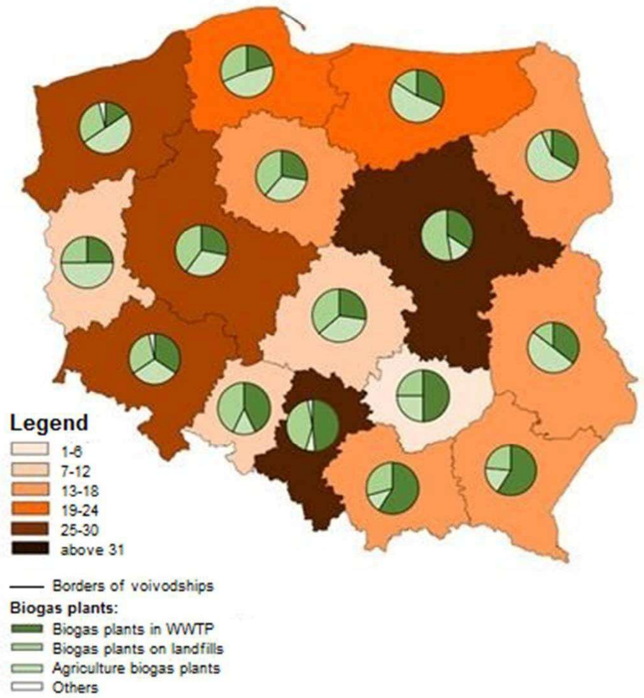

Fig. 4. Location of biogas plants in Poland [17].

In the areas of western and northern Poland and in the eastern part, agricultural plants form the dominant type of biogas plants.

The spatial distribution of the facilities is affected by the availability of agricultural waste in these areas. In the more industrialized parts of the country, biogas is derived from landfill gas obtained from wastewater treatment plants.

All biogas plants apply cogeneration, as electricity and heat are produced in a combined system in them.

The possibilities associated with further development of power plants burning landfill biogas and gas derived from wastewater treatment plants are already considerably limited. It is projected that within the next four years, we will face the building and commissioning of 700-800 of agricultural biogas plants.

Based on the document [16], in Poland until 2030 there is going to be on average one biogas plant in each commune (on condition that a commune has suitable conditions needed to launch such an enterprise).

In these circumstances, the estimated volume of biogas production after its purification could cover 10% of the annual domestic demand.

Alternatively, it could serve to completely meet the demands of the customers in the agricultural areas and deliver 125,000 MWh of electricity and 200,000 MWh of heat.

The increase in the application of agricultural biogas could contribute to the increase of the revenues from agricultural production obtained by farmers, while concurrently protecting the environment from pollution.

However, an enterprise involving the building of biogas plant does not appear to be easy and cheap. The investment needed for the construction of a single biogas plant coupled with an installation for gas purification (with the capacity of 1 MWel), capable of generating 3.5-3.8 million m^3 of agricultural biogas (52-60% of methane, i.e. accounting for around 2.5 million m^3 of biogas) is estimated at around 10-15 million PLN [12].

In case of biomethane production in the biogas plant, the biogas produced have to install additional units for cleaning gas because biogas must be drained and desulphurized, contained the proper value of H_2S and also directed to the installation treatment that removes primarily carbon dioxide from the gas.

The parameters which are the most important it is content of hydrogen sulphide (it should not exceed 7.0 mg/m^3) and calorific value (min 34.0 MJ/ m^3) like for high-methane natural gas (E5 group i.e., the minimum 86% methane content in biomethane) [3].

An important aspect, which determines the successive development of biogas installations, is associated with their high reliability and efficiency of the microbiological processes occurring in the bioreactors.

The location of biogas plants is determined by the environmental, economic, social, political, legal and technical-technology related considerations.

IV. Potential Biogas Production from Animal waste in Poland and Opole province

Currently, there is an interest in using animal manure as an energy feedstock for energy production due to rising energy prices and growing concerns. In agriculture and animal production sector, as in other branches of industry [18-22], the aim is to introduce the principles of the circular economy and sustainable development. The energetic use of animal waste as a substrate for biogas production is fully in line with this idea.

On the other hand, the inappropriate use of animal waste causes the environmental risks associated with its overuse in agriculture as fertilizers. This can lead to major environmental pollution caused by nitrates leaching to waters, therefore legal restriction about limitation of animal waste in agriculture have been introduced.

Typical manure management consists of removing manure from livestock buildings on a daily basis, then depositing it in piles, manure slabs or fields, where it is collected 2-3 times a year and spread for fertilization. During its decomposition, manure emits unpleasant gases such as ammonia and hydrogen sulphide and impacts the health and comfort of surrounding people [23].

According to FAO [24] total emissions from global livestock production are estimated about 7 Gigatonnes of CO_2-equiv per year, (which is about 14.5 percent of all anthropogenic GHG emission).

Due to above facts, an analysis of the possibility of producing biogas/biomethane from animal waste to generate electricity in one of Poland's regions - the Opolskie Voivodeship was carried out in comparison to national data based on information from 2020.

Animal production in Poland and Opolskie Voivodeship is presented in Table III.

Production of cattle (C), cows (Cw), pigs (P) and chicken (CK) were taken under account.

The calculations were performed on the basis of the following relations [7, 25]:

– annual amount of animal waste (MS)

$$MS = PA \times MG$$

– methane production (MP)

$$MP = MS \times DM \times OM \times PCH_4$$

– biogas production (BP)

$$BP = MP \times \%CH_4$$

– electricity production (EP)

$$EP = MP \times GCVCH_4 \times \eta_{EL}$$

where:

PA – animal population,

MG – amount of waste production per year,

DM – dry mass content,

OM – organic matter content in the waste,

PCH4 – potential for methane production),

%CH4 methane content in the biogas,

GCVCH4 – calorific value of methane (9.17 kWh/m^3),

η_{EL}– efficiency of electricity production (35% [26,27]).

TABLE III. ANIMAL PRODUCTION IN POLAND AND OPOLSKIE VOIVODESHP IN 2020 [17

Livestock	Population, head	
	in Poland	in the Opolskie voivodeship
Cattle in total (C)	6 343 728	129 034
Cows (CW)	2 468 059	44 102
Pigs (P)	11 727 410	331 847
Chicken (CK)	18 247 350	5 269 141

The daily amount of waste is 45 kg per bovine animal, 12.5 kg per swine, and 55 kg per cow, 0.05 kg/chicken [25,28].

The potential for methane production, methane content of biogas and other parameters of waste were taken from Table II as minimum value for each type of animal waste.

Calculations i.e., among others biogas production, and potential for electricity production are presented in Table IV.

Based on the data from 2020, it can be concluded that over 210 million tonnes of animal waste are generated in Poland per year.

The highest estimated biogas potential in the country and the Opolskie Voivodeship has cattle slurry (C), while the lowest concerns chicken farm waste (CK).

TABLE IV. THE ANALYSYS OF POTENCIAL OF ANIMAL WASTE

Type of waste		Amount of waste (MS) tonne/year	Biogas production (BP) m^3/year	Methane production (MP) m^3/year	Electric energy production (EP) MWh/year
Cattle	C1	104 195 732	750 209 273	1 250 348 789	4 012 994
	C2	2 119 383	15 259 561	25 432 632	81 626
Cows	CW1	49 546 284	481 589 885	802 649 808	2 576 105
	CW2	885 348	8 605 579	14 342 632	46 033
Pigs	P1	53 506 308	260 040 657	483 401 096	1 391 001
	P2	15 14 052	7 358 292	12 263 821	39 361
Chicken	CK1	330 139	94 409 430	157 349 051	505 012
	CK2	96 162	2 726 188	4 543 646	14 583

1 - for Poland; 2 - for Opolskie Voivodeship

In total, waste from livestock farming can generate 8,484,112 MWh/year of electricity on the national scale and 181,602 MWh of electricity/year on the scale of the Opolskie Voivodeship.
The total animal waste can generate 1,586,249,246 m^3/year of biogas in Poland and 33,949,620 m^3/year in the voivodship.

During the year, Poland uses over 18 billion m^3 of gas, including 4 billion of its own resources. By using the potential of only animal waste, it can significantly reduce the external demand for this raw material. The installations planned soon may produce 4 billion m^3 of biomethane annually within 10 years, which would constitute 20% of the national demand for gas [3].

V. Conclusions

Currently, special attention is paid to the unused potential of waste for biogas/biomethane production and animal manure can be used as the feedstock materials for biogas plants.
It was estimated that about 220 million Mg of animal manure Mg per year is produced in Poland which can give electricity energy production on the level about 8.5 mln MWh/year.
Poland is a country with a considerable potential for biogas production, which can be applied in the methane fermentation process, among others based on this waste.
Plans of European Community to decarbonize Europe and minimize GHG emissions as well as introducing to the market circular economy can be influenced on the development of biogas/biomethane sector.
An additional advantage of the development of biogas and biomethane plants is the fact that local communities can benefit from building new facilities by establishing for example an energy cluster or an energy cooperative, members of these groups can become energy self-sufficient.
All the benefits confirm that it is worth for the municipalities in Poland to invest in biogas plants.

References

[1] European Commision 2030 Climate & Energy framework https://ec.europa.eu

[2] Energy from renewable sources in 2020, Statistics Poland, Warsaw 2021

[3] Raport biogaz w Polsce, Magazyn Biomasa, 2021.

[4] M. Persson, J.A. Wellinger, "Biogas Upgrading to Vehicle Fuel Standardsand Grid Injection, IEA, *Bioenergy*, 2006.

[5] A. Fontana, V. Patrone, E. Puglisi, L. Morelli, D. Bassi, M. Garuti, L. Rossi, F. Cappa, "Effects of geographic area, feedstock, temperature, and operating time on microbial communities of six full-scale biogas plants", *Bioresour.Technol*. vol. 218, 980-90, 2016.

[6] M. Franco-Morgado, C. Alcántara, A. Noyola, R. Muñoz, A. González-Sánchez, "A study of photosynthetic biogas upgrading based on a high rate algal pond under alkaline conditions: Influence of the illumination regime", *Sci. Total Environ*. vol. 592, 419-425, 2017.

[7] M. Pawlita, M. Wzorek M., „Assessment of application of selected wastes for production of biogas", *E3S Web of Conferences*, vol. 19, 02017, 2018. DOI:10.1051/e3sconf/20171902017

[8] M. Pawlita, M. Wzorek M., „Analysis of domestic sewage treatment system", Chemik, vol. 10/70, pp. 620-625, 2016.

[9] N. Scarlat, J.F. Dallemand, F. Fahl „Biogas: Developments and perspectives in Europe", *Renewable Energy*, vol. 129, 457-472, 2018.

[10] K. Vorbrodt-Strzałka, K. Pikoń, „Environmental impacts associated with production and utilization of agricultural biogas, *Archives of Waste Management and Environmental Protection*, vol. 15/4, 1-12, 2013.

[11] E. Woźniak, „Condition of biogas plants in Poland", *Czysta Energia*, No. 1 2017.

[12] http://biogazowniawgminie.pl/artykuly/substraty-do-produkcji-biogazu-z-czego-produkowac-biogaz/

[13] M. Pawlita, M. Wzorek M., Płaczek M., „The influence of temperature on algal biomass growth for biogas production, *MATEC Web of Conferences,* vol. 240, 04008, 2018.
DOI:10.1051/matecconf/201824004008

[14] T. Michalski, „Biogazownia w każdej gminie – czy wystarczy surowca", *Wieś Jutra*, No. 3/128, 12-14, 2009.

[15] Office for Energy Regulation. https://www.ure.gov.pl/

[16] Poland's Energy Policy until 2030, Ministry of the Environment, Warszawa, 2009.

[17] Central Statistical Office, Information and Statistical Elaborations, Energy from Renewable Sources in 2015, Warszawa, 2016. www.stat.gov.pl.

[18] A. Król "The role of the silica fly ash in sustainable waste management" *E3S Web of Conferences*, vol. 10, s.1-5, 2016, DOI:10.1051/e3sconf/20161000049

[19] I. Kłosok-Bazan, "Innovations in industrial water preparation in a metallurgical plant," *Metalurgija*, vol. 55, no. 1, 2016.

[20] K. Mizerna, A. Król A., A. Mróz „Environmental assessment of applicability of mineral-organic composite for landfill area rehabilitation" *E3S Web of Conferences*, 2017, vol. 19, s.1-4. 2017, DOI:10.1051/e3sconf/20171902020

[21] I. Kłosok-Bazan, "Use of nanosilver for water conditioning in cooling tower circulation system", *Ochr. Sr.*, vol. 36, no. 2, 2014.

[22] J. Boguniewicz-Zablocka, I. Klosok-Bazan, A.G. Capodaglio, J. Ploskonka "*Planning the optimal solution for wastewater management in rural areas - case stu*dy", *MATEC Web Conf.*, vol. 174, 2018.

[23] G. Soyer, E. Yilmaz E. "Waste management in dairy cattle farms in Aydın region. Potential of energy application", *Sustainability*, *12*(4), 1614, 2020.

[24] FAO https://www.fao.org/news/story/en/item/197623/icode/

[25] J.J. Chávez-Fuentes, A. Capobianco, J. Barbušová, M. Hutňan, M. "Manure from our agricultural animals: A quantitative and qualitative analysis focused on biogas production", *Waste Biomass Valorization* vol. 8, 1749–1757, 2017

[26] M. Tańczuk, W. Kostowski, M. Karaś, "Applying waste heat recovery system in a sewage sludge dryer–A technical and economic optimization", *Energy Convers. Manage*. vol. 125, 2016.

[27] M. Tańczuk, W. Kostowski, „Technical, energetic and economic optimization analysis of selection of heat source for municipal sewage sludge dryer", *Energies*, *14*, 316 2021.

[28] M. Wzorek, „Physical and chemical properties of fuel containing animal waste", *WIT Trans. Ecol. Environ.* vol. 109, 69–77, 2008. DOI: 10.2495/WM080081

Evaluation of Water Quality Influence on Power Plant Cooling System

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***Abstract*—In the power plants water is widely used in many technological processes. In order to generete electricity is necessery to have constant access to sources of fresh water with its appropriate physical and chemical properties. This work present analysis of parameters in cooling water for maintenance of proper operating parameters of power plant. Cooling water quality can affect power plant performance. In this work water in selected close cooling systems was evaluated for their chemical constituents. Each constituent was analyzed individually to determine possible influence of the maximum allowable concentration on cooling plant perfomrance. Selected water quality parameter was correlated using Pearson coefficient to connect infuence of make-up water to system water parameter. Maintaining water balance, betweent both are the greatest challenges for water in power plant cooling efficiency improvment.**

Keywords—*cooling water quality, energy power plant, make-up water parameters correlation*

I. Introduction

The world's power plants face challenges to minimalize the gap between the water resources and the demand that increasing due to the rapid industrialization and urbanization [1]. More and more ofen the problem of closing water circuits and water renewal is considered [2]. In power plant water circuits are as well important as fuel that is used. Some alternatives fuels with sewage sludge or animals waste are often proposed [3]. In Eastern Europe, electricity is produced by thermal, hydro, wind and solar power plants. The most energy is generated by thermal power plants using hard coal. The process of generating electricity in a conventional hard coal power plant is three-stage. The first step is the conversion of fuel into thermal energy in the combustion process, where the heat heats the condensate to the appropriate steam parameters. The next step is to transfer thermal energy to mechanical energy directly to the blades of the steam turbine. The last step is the transfer of mechanical energy to electrical energy, using a generator.

In the technological process where water is used it is possible to distinguish three most important systems: Air-combustion system - exhaust gases, in which the appropriate amounts of air supplied by means of fans are supplied to the boiler and fuel. A water-steam system in which the water in the pipes that receive heat is heated to the point, where it changes into water-steam mixture, then into saturated steam, to eventually turn into saturated steam, where it goes through a pipeline to the high-pressure part of the turbine. From the diesel part, the steam goes to the boiler for re-overheating and returns to the medium and low-pressure part, where after the conversion of energy from warmer to mechanical steam expands in the capacitor in which there is a vacuum [4]. The purpose of the main cooling water system is supply cooling water to the condenser of the steam turbine, motor water coolers, vacuum pump coolers and compressor coolers (backup power supply); receive heat from the steam-water circuit using a condenser; receive heat from the closed operating water system using water-to-water heat exchangers and from vacuum pumps through appropriate coolers; and supply of water from the cooling tower to the process water tank of the wet flue gas desulphurization installation, and to the common process water tank in the gypsum dewatering building, and to the installation of fire water pumps. and washable water pumps. A power output system that includes a turbine-compressed generator and a voltage-increasing block transformer [5]. Closed-cycle cooling systems receive their cooling water from and return it to a cooling tower or basin. Due to evaporation and reffreshing of cooling water regular additions of fresh "make-up" cooling water are necessery. Quality of make up water and system water are diffrent due to continuos circulation of the second one.

The aim of the study was to analyze the quality of water in a closed-cycel cooling system of the power plant and its impact on the functioning of the circuit. The cooling water treatment system existing in the power plant was discussed. The water chemistry parameters like ph, conductivity, chlorides, silicia, sulphates, Magnesium and sodium ions, hardness, alkalinity and suspended solids were analyzed for a typical coal power plant. The effect of the individual water quality parameter in make-up and cooling water were correlated to evaluate influence on corrosion, biofilm and scale formation.

II. Materials and Methods

A. Water Treatment Plant for Power Plant System

In the considered power plant, cooling water is obtained from the station on the river, the captured water is pumped through pipelines to the water treatment plant (WTP). Raw water from the river is characterized by a variable content of organic carbon, which depends on the season, water temperature and summer blooms of plankton, after which decomposing dead organisms appear. The main task of the water treatment plant is to remove organic pollutants and compounds of manganese, iron and aluminum. In each type of cooling system, undesirable reactions and phenomena occur, such as the release of calcium and magnesium carbonate deposits or the formation of biofilm. Raw water parameters are presented in Table I. Water quality parameters was measured in accordance with the standard method for the examination of water and wastewater [6]. Water treatment plant preper water in order to avoid undesirable phenomena.

The pre-treatment plant is designed for the treatment of the raw water supplied from the intake and its preparation for further use as water to replenish cooling circuits and water for demineralization stations in order to further prepare it as water for replenishment of water-steam circuits of power boilers in the Power Plant.

The source of raw water for the needs of the Power Plant is the surface water intake located on the river. Raw water taken from the river is characterized by a variable content of organic carbon, which is largely influenced by summer blooms of plankton, and as a result, the emerging products of the decomposition of dead organisms. Therefore, the basic task for the installation of pre-treatment of water is to remove organic impurities and compounds of iron, aluminum and manganese [7].

TABLE I. RAW WATER FROM RIVER INTAKE

Parameter	Unit	Value
pH	-	6.8–10.1
Total hardness	mval/l	1.64–3.19
Sulphates –SO_4	mg/l	47–80
Silica- SiO_2	mg Si/dm^3	20–24
Iron Fe	mg /dm^3	0.04–2.01
TOC	mg C/dm^3	8.2–14.4
Conductivity	µS/cm	300–445
TTS	mg /l	1–30.6
COD	mgO_2/l	9–55.2
Total alkalinity	mval/l	1.15–1.79
ClorinesCl^-	mg/l	20–27
Nitrates –NO_3	mg/l	0.2–12

The pre-treatment water treatment system is designed on the basis of the following technological processes:

- Pre-filtration on slotted filters: the task of self-cleaning filters is to mechanically purify water from impurities over 1000 µm in size. The contaminated medium flows into the lower part of the filter and flows through the filter cartridge from the inside to the outside and flows out through the outlet connector in the side wall of the upper part of the filter.
- Pre-oxidation with ClO_2: Each of the four technological lines of pre-treatment of water is equipped with devices allowing for independent treatment. The pre-oxidation process takes place in the pre-oxidation chambers preceding the coagulation and pressure flotation chambers. In order to obtain full mixing of the oxidizer (ClO_2) with raw water, a static mixer DN 600mm is installed on the pipeline in front of the pre-oxidation chambers.The design of the chamber guarantees full utilization of its capacity thanks to the use of piston flow. Maintaining such flow conditions and using a two-point power supply for the rapid mixing chambers allow pre-oxidation to be carried out at different reaction times. For the nominal capacity of the technological line, this time is 5 or 10 minutes. Each of the pre-oxidation chambers is equipped with remote level measurement.
- Coagulation with aluminum sulphate, flocculation, pressure flotation: The coagulation process together with pressure flotation, as an element of post-coagulation suspension separation, is carried out in a system of four two-section technological lines. Each section consists of: coagulation chamber (fast mixing), flocculation chamber I°, flocculation chamber II°, pressure flotation chamber.

The fast mixing process is carried out in reinforced concrete coagulation chambers combined on the one hand with oxidation chambers and flocculation chambers on the other hand. Each technological line has separate chambers, i.e. in total in the WTP building there are 8 chambers of fast mixing.

Pressure flotation is one of the flotation methods that uses the phenomenon of the formation of a permanent agglomerate composed of a dispersed phase (aggregates of post-coagulation suspensions) and gas bubbles. Bubbles in the pressure flotation process are formed as a result of decompression of saturated water, which was previously saturated with atmospheric air under increased pressure in saturators.

The agglomerate formed as a result of the combination of lint and bubbles has a density lower than the density of water and is carried to the surface of the liquid [8]. Contaminants floating to the surface in the flotation chamber float on the surface of the water and are periodically discharged from the flotation chamber through the surface scraper and continue to flow gravitationally to the intermediate tanks of the flotate. In the flotation tank within the walls of the chamber there is a set of nozzles supplied from the economic water collector for continuous flushing of sediments from the walls of the tank. In order to improve the parameters of the compaction process, polyectrolite from the polyelectrolyte preparation station consisting of two electrolyte preparation and supply lines is dosed to the flotate fed to the flotate fed to belt thickeners. The fast filtration process is carried out on 16 open gravity filters with a total filter area of 1140 m^2. The process of filtration and rinsing of the bed is carried out using drainage of filters made of modules in the form of plastic blocks, connected to the gasket and forming drainage laterals. The spaces between the laterals are filled with concrete in a way that forms a uniform bottom of the filter chamber.

Dusty carbon is dosed separately into the water flowing into each of the rush filters. The dosing of dusty carbon into individual filters is based on a real-time analysis of the filtrate quality. The use of this element requires verification of the scope of analyzes performed after individual hasty filters. The idea of adapting the hasty filter to conduct dynamic sorption is to work out the filter bed immediately after rinsing by increasing the dosage of dusty carbon per bed, and then, after obtaining a stable effect of removing impurities, stopping dosing. On-line quality control of the filtrate allows to capture the moment of depletion of the sorption capacity of coal accumulated in the filter bed. When the quality of the filtered water deteriorates, the dosing of coal is automatically switched on directly to the supply of a given filter chamber.

As part of the pre-treatment of water in the system of pre-oxidation, coagulation, flocculation and pressure flotation, four technological lines were separated. On each of the strings, the treatment process can be carried out independently. Each of the strings has: the possibility of independent work, independent possibility to adjust the capacity, independent possibility to adjust the technological parameters of individual unit processes, independent dosage of reactants.

B. Cooling Tower and Cooling Water Pumping Station

The principle of operation of the cooling tower is simple and consists in the pumps supplying cooling water to the sprinkler, and then this water is dissected over the surface. During the descent of water, it gives off heat to the air, which moves upwards counter-current due to the chimney draught [9]. A cooling tower is a specific contact wet heat exchanger. Inside the cold store, the water is cooled by heat exchange between water and atmospheric air [5]. The cooled water is used to cool the turbine condenser. Cooling water is taken from the cooling pool by cooling water pumps flowing through the filtration system, where mechanical cleaning of cooling water takes place on two basic devices, i.e. gratings and rotary sieves. Each of the filtration stations consists of two independent, monolithic reinforced concrete channels. The cooling tower pool is supplemented with water from the WTP with two pipelines.

The six drip or waterboard filling zones are served by 8 locks (slide valves) of the main waterboard and an anti-icing pipe (with two supply channels). The locks are opened electrically and controlled by the DCS system. During a power failure, it is possible to operate the locks using available manual wheels, while direct access to the locks is impossible (they are available when the block is stationary). The defrosting pipe is installed around the perimeter of the cooling tower above the air intake. The defrost pipe forms a water curtain around the air intake, which limits the flow of air through the cooling tower. Although the anti-icing pipe consists of two parts, it must be used as one whole.

III. Results and Discussion

A. Analysis of Cooling Water Parameters

The basis for assessing the suitability of water for cooling is the analysis of the most important parameters that affect the functioning of circuits. The parameters that were taken in the analysis along with the suggested values according to the guidelines from the operating instruction for the cooling water pumping station are presented in Table II. There are no specific requirments set by Polish law for cooling water system in electruical power plant, each plants has its own instruction with reccomendation for such values.

The water quality parameters like pH, Electrical Conductivity (EC), Turbidity, Total Hardness (TH), chloride, sulphate, silicia as the base parameter are analysed. The monitoring frequency for most of them was daily, only TOC and Silicia weekly.

The pH values (Fig. 1) determines the dynamics and direction of corrosion processes. Too acidic or too alkaline reaction can negatively affect construction materials. For the power plant in question, the pH of the cooling water is maintained above 8. For a refrigeration environment, the pH must be maintained at least 7 to prevent the effects of corrosion, the corrosivity of concrete can be reduced by maintaining pH values from 8–8.5. Analyzing the average pH values in individual months, there are no great fluctuations in pH, in second part of the year, in firsth 3 months

TABLE II. Requirments for Recirculating Cooling Water

Recirculating cooling water		
Parameter	***Unit***	***Value***
pH	-	7.5–8.5
Temperatura	°C	14–35
Conductivity	µs/cm	<1600
Alkalinity	mval/l	<10
Chlorides	mg/l	<1000
Siarczany	mg/l	<450
Total hardness (TH)	mgCaCO3/l	< 500
Turbidity	NTU	<8
TOC	mg/l	<20
SiO - Silica	mg/l	<35
TSS	mg/l	<25

changes was meaningful but nevertheless all of them ensure safe functioning of the system considering that corrosion is a function of pH.

Electrical conductivity (EC) (Fig. 2) is a measure of dissolved ionic species in water. Analyzing the graph showing the EC, it can be seen that in some cases EC was above the permissible value. Conductivity in water means the ability of water to conduct electricity. EC increases with increasing ion content [7]. A higher value of ions can cause the formation of sediment. EC outside of range could cause metal corrosion and salt deposition on the heat exchanger tubes.

Alkalinity (Fig. 3) determines the ability of water to neutralize mineral acids . In the case of analysis of the above graph, exceeding the value indicated in the instructions was not observed. The level of alkalinity is determined by bicarbonates and carbonates present in water. Alkalinity is also determined by salts of weak inorganic and organic acids. General alkalinity is responsible for carbonate hardness, which is undesirable in the water management of power plants. React with a hardness to form scale Proper alkalinity of water allows us to maintain the pH at the intended level.

The chloride content (Fig. 4) in the system was measured daily, it varies from 90 [mg/l] to 136 [mg/l]. Excessive amounts of chlorides in water contribute to corrosion, so it is important to maintain them at the right level. Analyzing the graph, it can be concluded that maximum value of chlorides in the cooling water was not exceeded. Chloride ensures proper water chemistry, but it is the most aggressive agent in corrosion.

Sulphate (Fig. 5) values range from 219 [mg/l] to 334 [mg/l]. Analyzing the graph, it can be concluded that in no month the maximum values of the concentration of sulfates in water were exceeded. This means that the water in the system does not threaten the equipment and fittings. Sulfates in cooling water pose a risk of corrosion in concrete, pump components and cooling tower. Sulfurions in combination with chloride ions are catalysts for corrosion. The only way to reduce the concentration of sulfates in water is to discharge water.

Total hardness (TH) (Fig. 6) reflects presence of calcium and magnesium ions. The value for hardness ranges from 374 to 605 [mg $CaCO_3$/l]. We notice the highest values in the summer. Too hard water in the cooling system causes deposition of deposits, which can translate into improper operation of the equipment and inadequate heat dissipation, because the scale deposited in the tubes can significantly reduce the efficiency of the system. Most often, the values of water hardness oscillate around 400 [mg $CaCO_3$ /l]. Increased hardness parameters cause scaling and salt deposition.

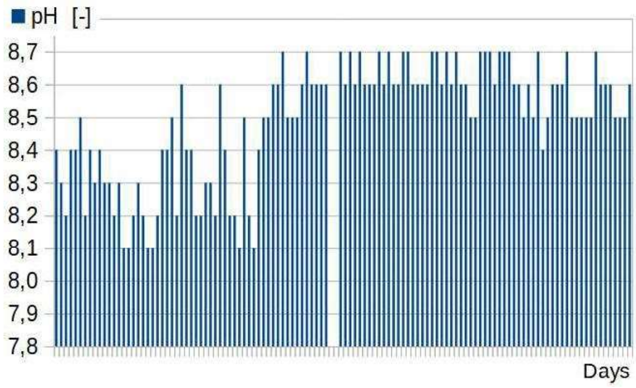

Fig. 1. pH for cooling system water.

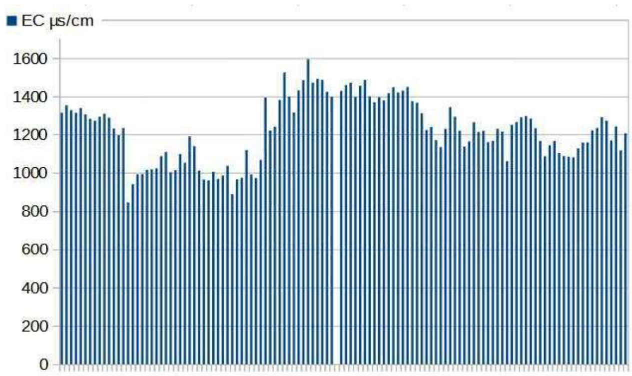

Fig. 2. Electrical conductivity (EC) for cooling system water.

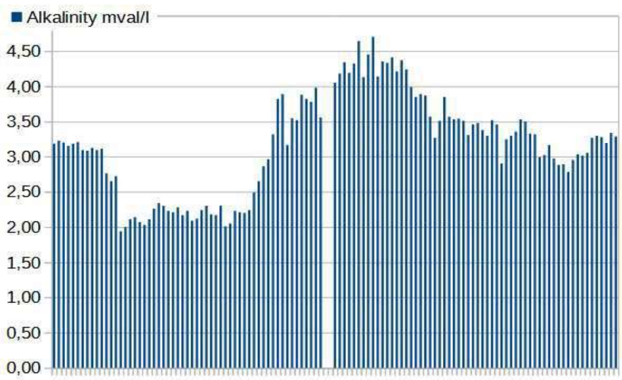

Fig.. 3. Alkalinity for cooling system water..

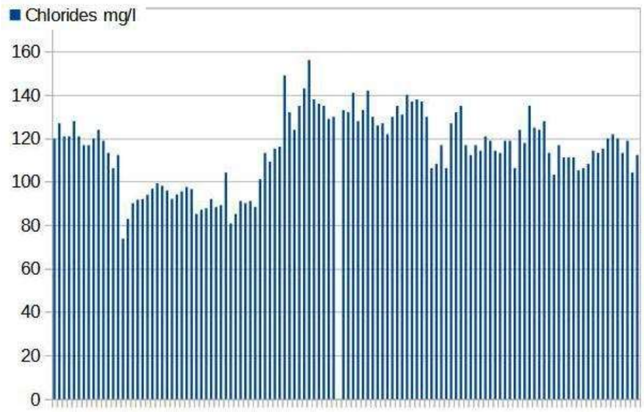

Fig. 4. Chloride for cooling system water.

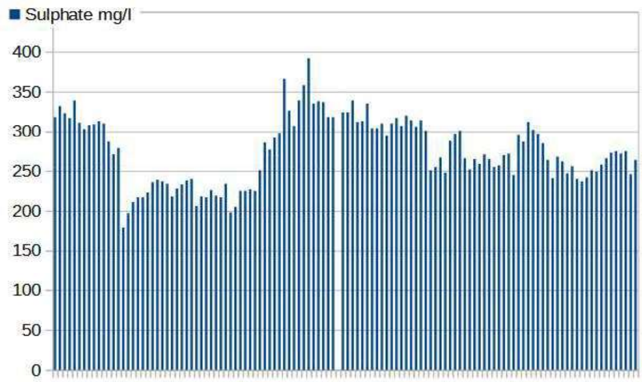

Fig. 5. Sulphate values for system water.

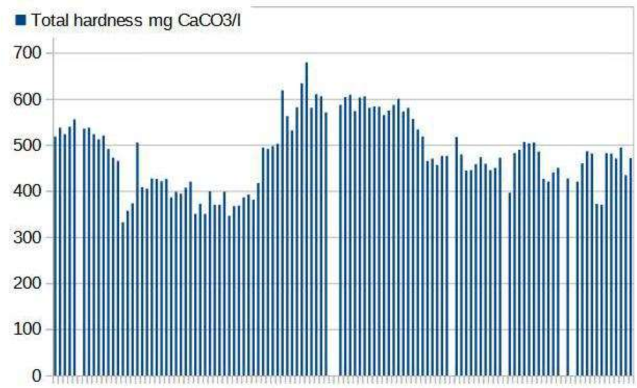

Fig.. 6. Total hardness values for system water.

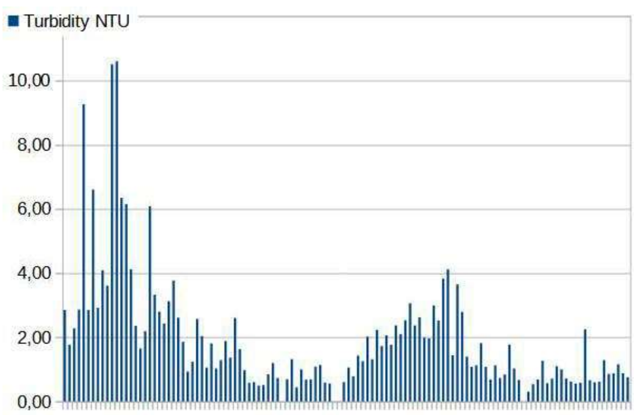

Fig.. 7. Turbidity values for system water.

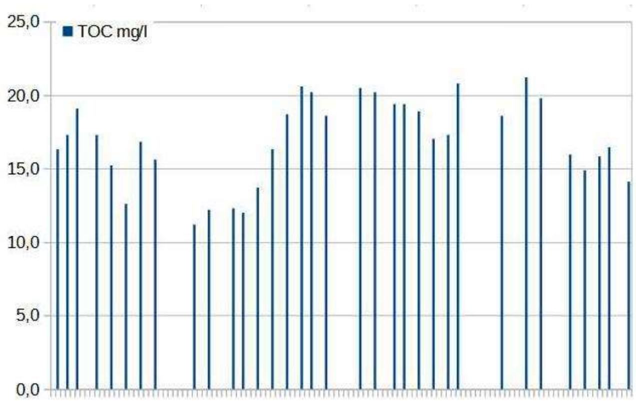

Fig. 8. TOC values for system water.

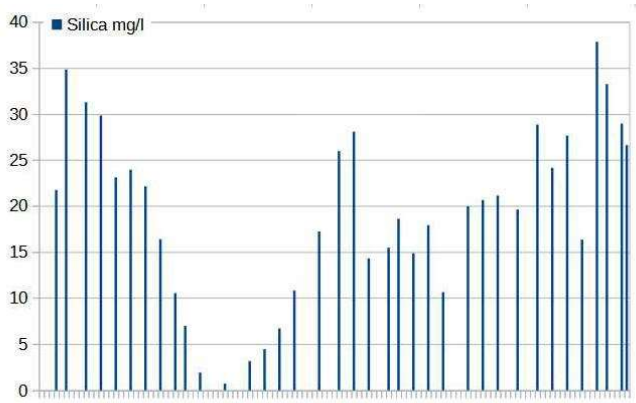

Fig. 9. Silicia values for system water.

Water turbidity (Fig. 7) is used to measure the presence of insoluble particulates in the system. Particles of sand, clay, iron, manganese enter from inorganic substances [11]. For the water analysed in the graph above, the value in few days was exceeded. Turbity measurments interferes with equipment operation, chocking of the equipment.

Total organic carbon (TOC) (Fig. 8) was measured weekly and is the amount of organic compounds contained in the tested water sample, it is a breeding ground for microorganisms. Substances that contain carbon and other elements, forming organic compounds. A high concentration of total organic carbon in water can damage equipment and negatively affect the ecosystem. The lowest value of the analyzed water is 11.9 [mg/l] and the highest is 21.87 [mg/l]. The analyzed sample does not exceed the permissible limit value.

Silica, was measured weekly, it ensures proper water chemistry. Silicia which is deposited on pipelines and walls, creates a layer that is difficult to remove, which can translate into a decrease in thermal efficiency. Silica as a result of rock degradation is part of most surface waters. Silica causes scaling and fouling problems. The minimum silica content in the sample is only 3.19 [mg/l] and the highest is 29.59[mg/l] According to the requirements, the norm of silica content in the tested water is not exceeded.

B. Water Make-up Requirments

The make-up water is added into the system in the volume depended on evaporation, blowdown, and other losses. Make-up water quality parameters requirments are more restrictive than for water already in circulation.

Trend analysis of the system water chemistry allow to determine the limiting parameters and improve the operation of the water cycle. Table 3. presents the make-up water quality requirments in the studied power plant.

TABLE III. RECOMMENDED MAKE-UP WATER QUALITY

Make -up water quality		
Parameter	***Unit***	***Value***
pH	[-]	8.3–9.6
Total hardness	ppm as $CaCO_3$	≤ 0.3
Iron	mg Fe/dm^3	≤ 0.01
Copper	mg Cu/dm^3	≤ 0.003
Silica	mg Si/dm^3	≤ 0.02
Na^+ and K^+	mg /dm^3	≤ 0.01
TOC	mg C/dm^3	≤ 0.2
Conductivity	µS/cm	≤ 0.1
TTS	mg /dm^3	1

Cooling system water and make-up water correlation was determined using a linear relationship using Pearson's correlation coefficient, where |1| means perfect relation and 0 means no relation [12]. Table 4 presents Pearson correlation results for selected parameters. Based on the table was possible to study the efect of make-up water parameters on the system water chemistry condition.

TABLE IV. PEARSON'S CORRELATION COEFFICIENT FOR COOLING WATER SYSTEM AND MAKE-UP WATER

	Cooling system water					
Make-up water	*pH*	*TH*	*Alk.*	*Silicia*	*EC*	*Chloride*
pH	0.72	0.54	0.42	0.38	0.81	0.56
TH	0.77	0.70	0.49	0.34	0.71	0.6
Alk.	0.44	0.64	0.60	0.23	0.69	0.47
Silicia	0.45	0.10	0.31	0.40	0.44	0.37
EC	0.55	0.69	0.47	0.29	0.34	0.60
Turbidity	0.43	0.40	0.37	0.21	0.60	0.30

A significant correlation was obtained for make-up water pH, harness, conductivity and chloride. Similar linearly correlation was observed in others resercher [13]. The system water conductivity are infuenced by the make-up ph, harness and turbidity The hardness of the system water is not governed by the make-up conductivity or chloride content. From those correlation, result that make-up water parameters like conductivity or alkalinity has a noticeable infuence on the system harness.Further better system operation data study are necessery to maintain the system water hardness levels in proper level.

The other make-up water parameters content does not afect the system water quality parameter to a signifcant level since their levels are minimal in make-up water.

D. Condenser Performance Relative to Stone Thickness

In closed cooling systems, scale deposition is a significant problem. This has a significant impact on the performance and service life of the entire system. Heat transfer and efficiency of devices are reduced.

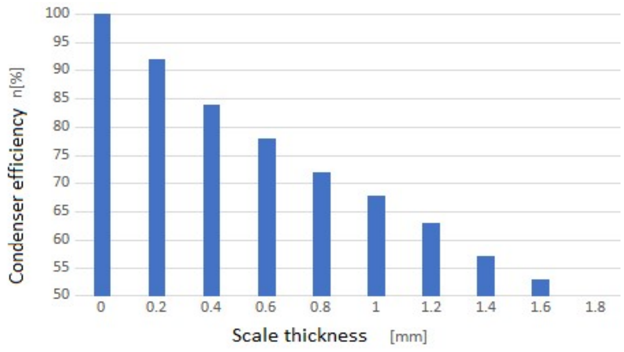

Fig. 10. Concenser efficiency in funcion of scale thickenes [based on 14]

The graph shown above clearly shows how much the scale thickness affects the condenser's efficiency. Any agent that can cause various types of deposits should be eliminated as far as possible. Frequent testing of cooling water samples allows early detection and avoidance of deposit formation. Analysis and selection of appropriate water parameters increases the efficiency of not only the condenser, but also all devices in the cooling water system.

Based on the above analyzed parameters of cooling water, it can be concluded that the hardness of water has a significant impact on the deposition of stone.

In order to maintain the correct parameters of cooling water, a number of chemicals are dosed into it, min. antiscalant, dispersant. Taking into account that cooling water and cooling tower due to its temperature, the fluctuations of which are very low, creates an ideal environment for the multiplication of microorganisms, and thus the development of biofilm, which negatively affects the operation of devices. The reduction of heat transfer by biofilm can be four times greater than in the case of calcium carbonate sediment. In addition, metabolic processes occurring in microorganisms cause corrosive phenomena leading to damage to the installation [15]. To avoid scaling, system water should be treated with scale preventing chemicals together with regular desludging.

IV. Conclusions

Thermal efficiency and proper operation of the power plant are related directly to the quality of the water in the cooling system. The first part of the work contains a technological description of power generation and preliminary water treatment, that are neceserry to understand the plant. In the next stage, an analysis of cooling water parameters in the selected period was undertaken. Maintaining water balance, betweent water system and make-up watre by maximizing the cycles of concentration, and minimalization of blow down are the greatest challenges for water in power plant efficiency improvment.

In most of the systems, hardness, silica, and conductivity play a signifcant role. This study highlights the importance of studying, analyzing, and decision making in individual systems rather than applying existing guidelines. The concept of dosing a additional chemicals, that could increase the efficiency of circulation, especially in the summer months, when there are the most microorganisms in the water, and power plants struggle with the occurrence of algae, which reduces the efficiency of cooling systems was also analyzed. Nevertheless, there is a danger of these particles entering the sewage, and could not meet discharge limit. It is therefore reasonable to control the parameters of system water and make-up water to prevent undesirable phenomena.

References

[1] M. Shafei, S.H. Moosavirad, A. Azimifard, and S. Biglari, ”Water consumption assessment in Asian chemical industries supply chains based on input–output analysis and one-way analysis of variance,” Environ Sci Pollut Res 27. 2020, pp. 12242–12255.

[2] J. Boguniewicz-Zabłocka, and I. Kłosok-Bazan, ”Sustainable Processing of Paper Industry Water and Wastewater: A Case Study on the Condition of Limited Freshwater,” Resources.Polish Journal of Environmental Studies,29(3), 2020, pp.2063-2070.

[3] M. Wzorek, ”Assessment of leachability of harmful components from alternative fuels prepared with the use of sewage sludge,” Ecological Chemistry and Engineering, no 19(4), 2012, pp. 617-627.

[4] M. Lech, ”Power plants and their equipment,” Elektrownie i ich urządzenia. *In Polish*, Politechnika Wrocławska , 1981, Wrocław.

[5] D. Laundyn, M. Pawlik, and F. Strzelczyk, ”Power plants,” Elektrownie. *In Polish*, Wydawnictwo naukowo-techniczne 1990, Warszawa.

[6] AWWA, ”Standard methods for examination of water and wastewater,” 1998.

[7] J. R. Dojlido, ”Water chemistry,” Chemia wody, *In Polish*, Arkady, 1987, Warszawa.

[8] A. L. Kowal, J. Maćkiewicz, and M. Świderska-Bróż, ”Design basics of water purification systems,” Podstawy projektowe systemów oczyszczania wód, Oficyny Wydawnicza Politechniki Wrocławskiej, 1996, Wrocław.

[9] Cooling Towers Water Management, <hppt://waterCT.com>.

[10] Detailed instructions for the operation of the water-sewage network of Power Plant. Instructions for operation of the pre-treatment water plant. Based on Eng thesis Piotr Danisz. *In Polish*.

[11] A. Księżyk-Sikora, W. Pawlita, J. Piegsa, J. Sikora, and M. Sobczyk, ”Water and wastewater chemistry,” Chemia wody i ścieków, *In Polish*, Politechnika Śląska, 1978, Gliwice.

[12] S. Chandrasekaran, G. Sankaran Pillai, and B. Venkatraman, ”Spatial and heavy metal assessment in beach sands of east coast of Tamil Nadu, India,” Environ Nanotechnol Monit Manag 14:100324. *2020.*

[13] R. McCleskey, D.K. Blaine, J.N. Nordstrom, and J.W. Ryan Ball, ”A new method of calculating electrical conductivity with applications to natural waters,” Geochim Cosmochim Acta 77:2012, pp. 369–382.

[14] J. Marjanowski, and A. Nalikowski, ”Water quality in cooling systems,” *In Polish.*Jakość wody w układach chłodzenia, 2007.

[15] E. Podgórni, J. Boguniewicz-Zabłocka, and I. Kłosok-Bazan, “The Impact of Nano-Silver Doses on Microorganism-Deactivation Effectiveness in Water Circulating in a Cooling Tower Cycle,” *Polish J. Environ. Stud.*, vol. 24, 2015, pp. 2321–2327.

Water Quality Control as an Element of Increasing the Operational Safety of Energy Production Systems

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***Abstract*—Water, as well as the fuel, is the primary raw material use in the power generation process. The interdependency between water and energy, sometimes called the water-energy nexus, is growing in importance as demand for both water and energy increases and the increasingly difficult availability of these basic raw materials. Maintaining high quality water is the most important factor in preventing degradation of boilers and cooling towers. It is therefore necessary to be aware of the fact, that ensuring proper water quality is an important element of operational safety of energy production systems. The paper presents the results of research on the quality of water used in the conventional power plant. Constantly monitoring of available resources and possibility to adapt existing treatment systems to the changing quality of the raw water allows to increase the operational safety of energy production systems. The presented research concern both, the quality of water taken from the source and the water used in specific energy production processes. Despite the changes in the quality of water in the source (river), there were no exceedances of the quality parameters in water supplied technological processes, in the investigated period.**

Keywords—water quality, reliability, energy production systems, water-energy nexus

I. INTRODUCTION

For the average consumer of electricity, it is primarily fuel, gas, coal, oil or nuclear transformations that are needed to produce electricity. At the same time the interdependency between water and energy, sometimes called the water-energy nexus does not exist in the minds of the average person. Meanwhile it is growing in importance as demand for both water and energy increases [1]. Coal-fired power plants show high requirements of water, range from 1.37 m^3 per MWh (technology: gas-steam unit with integrated fuel gasification; cooling method: cooling tower), to 137.6 m^3 per MWh (technology: steam; cooling method: flow system) [2].

In Poland, the generation and supply of electricity, gas, steam and hot water used in 2020, 5 171.7 hm ^{3} of water (87% of total water consumption in industry). Most of the water used in the energy sector comes from surface water intakes. In Poland, in 2020 more than 5 160.7 hm ^{3} water was abstracted from the rivers and lake [3], [4]. Unfortunately, water shortages have recently been observed more and more frequently in Poland [5], meanwhile water is a limited and vulnerable resource, what's important, essential for life and development. Water shortages are the result of highly variable weather conditions and we must be aware that the problem will become more acute as a result of ongoing climate change. Meanwhile, water is a strategic raw material for the power industry, so droughts can be a serious challenge. Lack of water also poses a threat to the maintenance of power generation facilities as lack of fuel.

Each water source offers a unique water chemistry, and it is, therefore, very important to get complete analysis of the feed water for selecting appropriate treatment program for selected water circle [6]–[8]. The water quality can be influenced by many factors, including the types of wastewater treatment in a given region [9], leachate from agriculture and industrial facilities [10]. In any conventional power plant, two basic water circuits can be distinguished: the water/steam circuit and the cooling circuit [11].

In the steam-water circuit, demineralised water circulates in a closed boiler-turbine circuit, and it is this water which takes a direct part in the production of electricity. Water intended for making up losses in this circuit must meet the stringent quality requirements listed in Table I. The very stringent requirements presented in Table I arise from the need to ensure the safe operation of the turbines. Any deviation from the presented water quality carries the risk of damage to the equipment. High boiler water silica content can result in silica vaporization with the steam, and, under certain circumstances, siliceous scale. Silica content of the boiler water is not as critical for steam systems without steam turbines. High concentrations of suspended iron in boiler water can produce serious boiler deposit problems and are often indications of potentially serious corrosion in the steam or steam condensate systems. The content of the Total Suspended Solids (TSS) need be controlled, also. TSSe result from the precipitation in the boiler of feedwater hardness constituents due to heat and interaction of treatment chemicals, and from corrosion products in the feedwater. They can contribute to boiler tube deposits and enhance foaming characteristics, leading to increased carryover [12]

TABLE I. RECOMMENDED CIRCULATING WATER QUALITY IN THE WATER/STEAM CIRCUIT - SELECTED PARAMETERS [13]

Parameter	Unit	Level
pH	[-]	8.3–10 [a.] 8.8–9.6 [b.]
Total hardness,	ppm as $CaCO_3$	≤ 0.3
Iron	mg Fe/dm^3	≤ 0.01
Copper	mg Cu/dm^3	≤ 0.003
Silica	mg Si/dm^3	≤ 0.02
Σ Na^+ and K^+	mg /dm^3	≤ 0.01
TOC	mg C/dm^3	≤ 0.2
Conductivity	µS/cm	≤ 0.1
TTS	mg /dm^3	1

[a.] DOP<900 psig; [b.] DOP>900 psig

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The thermodynamic parameters of the steam produced in the system after some time prevent its further use for energy production purposes, it is necessary to condense it in a device called a condenser and return it to the boiler together with the make-up water. The cooling medium is also water, but with a much lower degree of purity than the water turned into steam. Therefore, a second water circuit is necessary, whose task is to condense the used steam before feeding it back into the boiler again [14].

TABLE II. RECOMMENDED WATER QUALITY REQUIREMENTS FOR COOLING TOWER RECIRCULATING WATERS - SELECTED PARAMETERS [13]

Parameter	Unit	Level
pH	[-]	6.8–7.2 [a.] 7.8–8.4 [b.] 7.0–7.5 [c.]
Total hardness,	ppm as $CaCO_3$	30–50 [d.] 200–250 [e.]
Iron	mg Fe/dm^3	<0.5
Copper	mg Cu/dm^3	≤ 0.1
Silicon Dioxide	mg Si/dm^3	150
Turbidity	NTU	0.1
TOC	mg C/dm^3	≤ 0.5
Conductivity	µS/cm	300–1500
TTS	mg C/dm^3	≤ 100

[a] Without scale inhibitor; [b] With scale inhibitor, [c] With phosphate present; [d] Carbonate hardness without scale inhibitor; [e] Carbonate hardness with scale inhibitor

Since water is a strong polar solvent, metallic materials tend to dissolve (corrode) in water and water solutions through mechanisms involving electrochemical reactions. The quality of water circulating in the cooling tower cycle will have a significant impact on its operation, and the cooling system operation can directly affect reliability, efficiency, and costs of many processes [15], [16]. The cooling system must address five major challenges for cooling tower maintenance. They include traditional issues such as: controlling inorganic scale deposition on cooling surfaces, providing corrosion protection for steel, copper, copper/nickel tubing, and cooper alloys, controlling microbiologic growth, including biofilms on cooling surfaces and bacterial counts in the cooling tower basin water, preventing fouling in heat exchangers and condensers and controlling airborne impurities and contaminants that enter external to the water source [5]. Modern challenges today for water in cooling system are to attain the appropriate methods without causing any harm through disinfection of by-products, which in turn requires the use of new chemical disinfectants [17].

Maintaining high quality water is the most important factor in preventing degradation of boilers and cooling towers. It is therefore necessary to be aware of the fact, that ensuring proper water quality is an important element of operational safety of energy production systems. There are many quite different types of risks incurred in the operation of an energy systems. In this paper, inadequate water quality in selected energy circuits is taken as a risk factor.

II. AVAILABLE WATER SOURCES FOR THE PRESENTED OBJECT

The analysed power plant is located in the catchment area of two rivers Odra and Mała Panew. The waters of these rivers were considered in terms of their usefulness for the water management needs of the planned power plant. After analyses of the chemical composition of the water, it was decided to locate the water intake on the Mała Panew River. The water in the Mała Panew River was much less saline than that in the Odra River. Taking water from the Mała Panew makes it possible to use it for a longer period in the cooling circuit of the power units, which multiplies the degree of salinity of the cooling water before it is desalinated and at the same time reduces water intake. The salinity of the water in the Oder River was twice as high as in the Mała Panew River (Table II). This can be explained by the influence of mining in the area through which the right inflow of the Oder, the Olza river. This negative impact of mine water on the water level of the Oder River seems to be confirmed by chloride and sulphate concentrations. Chloride concentration in Odra rage between 290 and 320 mg/L while in Mała Panew it was 20–27 mg/L. Sulphate concentration in Odra River on average was, while in Mała Panew it range between 47–80 mh/L. Water in the Oder River is also characterized by a higher hardness (Mała Panew 1.64–3.19 mval/L while Oder 5.56–6.21 mval/L). Only the concentration of silica favours water flowing in the Oder. Silica concentration in the studied period ranged from 20 to 24 mg/L in water abstracted from the Mała Panew River, while 7.2 mg/L in water abstracted from the Odra River 116, 5 mg/L. From the operational safety point of view important are also the indicators predicting the concentration of organic compounds in water. COD (Chemical Oxygen Demand) range in Mała Panew between 9–55 mg/L while in Odra River it was about 20 mg/L. TOC (Total Organic Carbon) in Mała Panew range between 8–14 mgC/L and was and was higher than that recorded in water from the Oder River (6 mgC/L). As a regards of total suspended solids Mała Panwe River show a large variation in concentration depending on the weather. During heavy rains and snowmelt it reach 30 mg/L.

However, suspended solids are a pollutant that can be easily removed from the water by sedimentation and filtration.

TABLE III. PHYSICAL AND CHEMICAL PARAMETERS OF THE WATER OF THE MAŁA PANEW RIVER AND OF THE ODER RIVER [18]

Contamination indicator	Unit	Determined values	
		Mała Panew	***Odra***
Conductivity	µS/cm	300–445	1132
pH	-	6.8–10.1	7.8
Silica	mg/L	20–24	7.2
Total suspended solids	mg/L	1–30	22
COD	mgO_2/L	9–55	20
Chlorides Cl^-	mg/L	20–27	311.7
Sulphates SO_4	mg/L	47–80	116.5
Total iron Fe	mg/L	0.04–2.01	no data
Aluminium	mg/L	0.071–0.123	b.l.d[a.]
Manganese	mg/L	0.196–0.382	no data
Alkalinity 'p'	mval/L	0–0.48	no data
Total alkalinity	mval/L	1.15–1.79	1.2–3.1
Magnesium hardness	mval/L	0.22–1	0.43–0.52
Total hardness	mval/L	1.64–3.19	5.56–6.21
Calcium hardness	mval/L	1.42–2.57	1.46–1.96
TOC	mgC/L	8–14	6
Nitrates NO_3	mg/L	0.2–12	3

[a] b.l.d.- below the limit of determination

Summarising the presented values, it should be noted that the main source of water for the power plant is the Mała Panew river, however, due dramatically changing climatic conditions, a target water intake from the Odra river cannot be excluded. However, it must be in mind that the cost of producing water from the Oder will be higher, which may affect the overall cost of power generation. It is also important to emphasise the need for monitoring of the water quality in the source. Some parameters of raw water should be monitored continuously, some should be monitored on a regular basis and some parameters should be monitored only occasionally. Each industrial consumer of the water should fully understand the impact of water from local source on energy production equipment, because sometimes the monitoring of the same parameter results in completely different conclusions. The monitoring practice normally include two approaches: laboratory and online analysis. Usually, laboratory methods are developed to achieve high accuracy of the analysis, while on-line instruments may not be extremely accurate, but obtains results in real time and on an ongoing basis. The combination of both approaches allows effective protection of water treatment equipment, which significantly increases the operational safety of the power plant.

III. Water Tretment

Due to the previously mentioned properties of water, it must be treated before it is used to supply energy facilities. The water treatment plant for the Power Station should be designed to produce water of the required quality for the particular plant equipment, independently of the water quality of the source.

In the facility analyzed in this paper there are the installation for preliminary water treatment is designed for treatment of supplied raw water from "Mała Panew" intake. Pre-treated water is use further treated as supplementary water for cooling circuits and water for demineralization unit as supplementary water for water and steam circuits power boilers. The installation for water pre-treatment consists of the following unit technological processes: The installation for water pre-treatment was designed based on the following technological processes:

- pre-filtration on slit filters;
- pre-oxidation with ClO_2;
- aluminum sulphate coagulation, flocculation, flotation;
- filtration on rapid filters and adsorption on activated carbon.

In order to increase the reliability of the facility's operation, the pretreatment system consists of 4 independent process lines which, in case of failure of any of the units, secure the water supply by the efficient operation of the other 3 lines. All technological installations of the treatment plant are equipped with elements of the water quality metering system, which enable the automatic control of technological processes. The pre-treated water is subjected to further treatment processes depending on which circuit it is directed to. Water demineralization units is used to improve the quality of water obtained after preliminary treatment in order to prepare it for replenishment of water and steam circuits of power boilers. The first stage of initial demineralisation is water heating carried out on three plate and slot exchangers with a nominal capacity of 75% of the required capacity of the entire system each, i.e. 225 m3/h. Then, water flow to the ultrafiltration process itself is based on the molecular sieve effect with a pore diameter of 0.01-0.1µm and involves the physical sieving out of compounds with a sufficiently high molecular weight. Due to the pore size of the membrane and the non-diffusive nature of the process, the operating pressure can be much lower than in reverse osmosis (RO) and in this case is about 3.5 bar. The flow of pre-treated water through the ultrafiltration modules is forced by pumps pumping water from the sub-filtration tanks to the UF. The UF node is equipped with auxiliary installations for backwash BW (Backwash), chemical backwash CEB (Chemical Enhanced Backwash) and a closed loop cleaning installation CIP (Cleaning In Place). The next stage of the water preparation system is reverse osmosis. Water purification on the reverse osmosis modules consists in its tangential flow to the walls of semi-permeable membranes at a pressure higher than the so-called osmotic pressure normally prevailing in the system, as a result of which water devoid of impurities (peremeat) permeates through the membranes, while the impure solution (concentrate) is caught on the membranes [4]. The last stage of water preparation is the purification stage, which consists of di-ion exchangers. Their task is to finally correct water quality parameters by removing trace amounts of ions not retained by the preceding technological units.

IV. Quality of Water Use in Energy Production

Security of supply of electricity to final consumers is related to the necessity to ensure sources of water, which will not affect the condition of the power generation equipment. Constant monitoring of the quality of water supplied to particular water circuits, contribute to improving this safety.

The results of such monitoring for important parameters, at three stages of water production, are presented in the Figures 1-2 and in Table IV-VI.

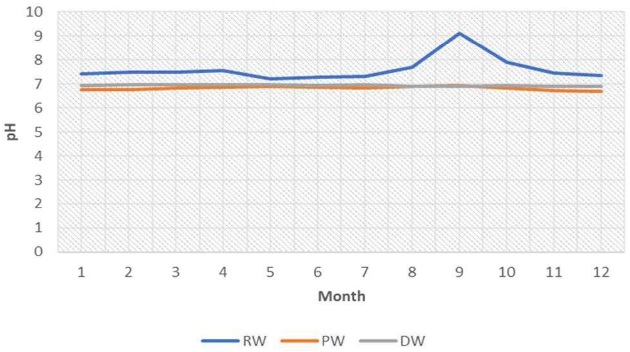

Fig. 1. Change in pH at the different stages of production *(RW-raw water; PW-pretreated water; DW-demineralised water)*

Fig. 2. Condactivity change at the different stages of production *(RW-raw water; PW-pretreated water; DW-demineralised water).*

Despite the variability of the source water, the water use to the system had a constant pH value. In the process of water heating and evaporation (with incorrect parameters), it is not uncommon for the pH of the water to change or for undesirable substances to be released. No such phenomenon was observed in the analysed facility. The level of conductivity at different stages was also analysed in detail. The results are presented in Fig. 2.

Despite significant changes in conductivity in raw (RW) and pre-treated (PW) water, the water supplied the water/steam circuit has a constant very low conductivity, not exceeding 0.1 μS/cm. It can therefore be concluded that the water fed into the circule is ultra-pure water. Maintaining the presented water level significantly influences the safety of devices operating in the system. This is confirmed by the other analysis results presented in the Table IV.

TABLE IV. CHANGE IN HARDNESS, SILICA AND IRON VALUES DURING PARTICULAR WATER TREATMENT PROCESSES

Month	Value	Hardness [mval/L]			Silica [mg/L]			Iron [mg/L]		
		RW(1)	PW(2)	DW(3)	RW(1)	PW(2)	DW(3)	RW(1)	PW(2)	DW(3)
January	medium	2.96	3.08	0.00	6.49	n.d.	0.002	56.32	0.007	< 0.01
	minimum	2.82	2.95	0.00	3.24	n.d.	0.001	0.75	0.005	< 0.01
	maximum	3.12	3.16	0.00	9.24	n.d.	0.005	56.32	0.012	< 0.01
February	medium	2.94	3.02	0.00	3.78	n.d.	0.001	0.76	0.007	< 0.01
	minimum	2.24	2.37	0.00	0.88	n.d.	0.001	0.59	0.005	< 0.01
	maximum	3.21	3.27	0.00	9.63	n.d.	0.003	0.93	0.015	< 0.01
March	medium	3.05	3.21	0.00	1.99	n.d.	0.002	0.57	0.007	< 0.01
	minimum	2.86	2.91	0.00	0.73	n.d.	0.001	0.30	0.004	< 0.01
	maximum	3.26	3.34	0.00	3.69	n.d.	0.004	0.85	0.007	< 0.01
April	medium	2.97	3.10	0.00	0.68	0.94	0.003	0.37	0.006	< 0.01
	minimum	2.05	3.00	0.00	0.13	0.34	0.001	0.24	0.005	< 0.01
	maximum	3.16	3.20	0.00	2.62	2.62	0.005	0.55	0.007	< 0.01
May	medium	3.05	3.12	0.00	3.79	3.42	0.002	0.39	0.006	< 0.01
	minimum	2.89	3.05	0.00	1.29	0.94	0.002	0.25	0.005	< 0.01
	maximum	3.16	3.23	0.00	6.67	5.11	0.003	0.75	0.008	< 0.01
June	medium	3.09	3.14	0.00	5.41	5.13	0.002	0.43	0.007	< 0.01
	minimum	2.67	2.88	0.00	1.55	1.51	0.000	0.43	0.005	< 0.01
	maximum	3.42	3.26	0.00	7.43	7.51	0.002	0.43	0.016	< 0.01
July	medium	2.94	3.01	0.00	4.38	2.65	0.003	0.45	0.008	< 0.01
	minimum	2.76	2.87	0.00	1.38	1.16	0.001	0.33	0.005	< 0.01
	maximum	3.07	3.13	0.00	6.44	5.12	0.008	0.56	0.015	< 0.01
August	medium	2.66	2.84	0.00	6.72	6.08	0.003	1.07	0.011	< 0.01
	minimum	2.32	2.43	0.00	5.33	4.99	0.001	0.43	0.005	< 0.01
	maximum	3.01	3.31	0.00	8.00	7.11	0.007	1.84	0.027	< 0.01
September	medium	2.44	2.622	0.00	9.70	7.56	0.003	0.74	0.010	< 0.01
	minimum	2.29	2.44	0.00	6.71	6.47	0.002	0.60	0.005	< 0.01
	maximum	2.58	2.82	0.00	10.43	8.25	0.007	1.00	0.019	< 0.01
October	medium	2.55	2.70	0.00	10.43	8.72	0.003	0.62	0.010	< 0.01
	minimum	2.28	2.58	0.00	7.51	7.34	0.001	0.48	0.005	< 0.01
	maximum	2.69	2.94	0.00	12.48	10.56	0.007	0.75	0.023	< 0.01
November	medium	2.69	2,82	0.00	10.88	8.90	0.003	0.54	0.009	< 0.01
	minimum	2.50	2.64	0.00	7.89	6.50	0.001	0.44	0.005	< 0.01
	maximum	2.86	2.96	0.00	13.20	13.00	0.009	0.84	0.018	< 0.01
December	medium	2.83	2.95	0.00	10.95	10.46	0.003	0.53	0.008	< 0.01
	minimum	2.70	2.89	0.00	9.04	9.40	0.002	0.44	0.005	< 0.01
	maximum	2.86	3.06	0.00	13.20	11.71	0.010	0.64	0.012	< 0.01

(1)raw water; (2)pretreted water; (3)demineralised water

Steam pollution is caused by an excessive content of dissolved substances and salts precipitated in the boiler water, which are carried with the steam flow into the turbine blades. By settling on the blades, they can cause disturbances in turbine operation, and sometimes they are the cause of serious failures. Preventing such situations by controlling the most important parameters of water should be an element of every system ensuring reliability of operation of power engineering facilities. One of such parameters is water hardness.

As far as hardness is concerned, the raw water is of medium hardness, allowing it to be used in a cooling system. For the water/steam system, the water is effectively softened, with all samples analysed showing the absence of hardness-causing compounds (Table IV).

Among the various impurities in the water/steam cycle, silica plays a special role due to its high solubility in steam. It belongs to very weak acids and its dissociation (ionisation) at pH 10 is not complete. 50% of the silica contained in boiler water remains un-ionised. This is what dissolves in steam. By closely monitoring silica concentration at key points in the circuit, plant efficiency can be managed more effectively, downtime can be reduced and costly repairs and stoppages can be avoided. costly repairs and shutdowns. The results of silica concentration analyses are presented in Table IV. The maximum silica concentration recorded at the plant was 0.01 mg/L. This level was incidental, as the average silica concentration in the object was 0.003 mg/L.

The control element of the system is the measurement of concentration of iron compounds in water. The results obtained for the analysed object are presented in Table IV. As can be seen, the incident of high iron concentration in the raw water (56 mg/L) did not affect the quality of water supplied to the circuits. Concentration on iron in pre-treated water was on the level 0.007 mg/L while in demineralized water was below the level of analytical determination.

Summarising the presented information on water quality derived from the summary of annual quality checks, it can be concluded that the treatment system ensures a high level of operational safety of the analysed power plant.

Water usage in power plants is and will be a critical issue for the power sector, especially in water-scarce areas. Progressive climate change in many European countries will lead to changes in available water resources both in terms of quantity and source quality. This in turn will make it necessary to constantly monitor available resources and to adapt existing treatment systems to the changing quality of the source water.

V. CONCLUSIONS

The goal of the energy policy is energy security energy security, while ensuring the competitiveness of the economy, energy efficiency and reduction of the impact of the energy sector on the environment, with optimum use own energy resources [19].

Security of supply of electricity to final consumers is related to the necessity to ensure that the demand for power and electricity by existing power plants. For the time being, electricity generation is inextricably linked to the need for access to water sources.

Constantly monitoring of available resources and possibility to adapt existing treatment systems to the changing quality of the raw water allows to increase the operational safety of energy production systems

REFERENCES

[1] E. Pawlowska, J. Machnik-Slomka, I. Klosok-Bazan, M. Gono, and R. Gono, “Corporate Social Responsibility of Water and Sanitation Company in the Czech Republic - Case Study,” Energies, vol. 14, no. 13, p. 3981, Jul. 2021.

[2] “Commission Recommendation (EU) 2021/1749 of 28 September 2021 on Energy Efficiency First: from principles to practice - Guidelines and examples for its implementation in decision-making in the energy sector and beyond”.

[3] D. Bochenek, U. Dawgiałło, and E. Gorzkowska, “Statistical analyses, Environment 2021, Content-related works.”

[4] J. Boguniewicz-Zabłocka, and I. Kłosok-Bazan, “Sustainable Processing of Paper Industry Water and Wastewater: A Case Study on the Condition of Limited Freshwater Resources,” Polish J. Environ. Stud., vol. 29, no. 3, pp. 2063–2070, Mar. 2020.

[5] I. Kłosok-Bazan, “Innovations in industrial water preparation in a metallurgical plant,” Metalurgija, vol. 55, no. 1, 2016.

[6] I. Kłosok-Bazan, “Use of nanosilver for water conditioning in cooling tower circulation system / Próba zastosowania nanocząstek srebra do kondycjonowania wody w obiegu chłodni kominowej,” Ochr. Sr., vol. 36, no. 2, 2014.

[7] A. Zahid, The Science and Technology of Industrial Water Treatment. London: IWA Publishing - Taylor and Francis Group, 2010.

[8] I. Zimoch, E. Bartkiewicz, J. Machnik-Slomka, I. Klosok-Bazan, A. Rak, and S. Rusek, “Sustainable Water Supply Systems Management for Energy Efficiency: A Case Study,” Energies, vol. 14, no. 16, p. 5101, Aug. 2021.

[9] M. Pawlita and M. Wzorek, “Analysis of domestic sewage treatment system,” Chemik, vol. 10, no. 70, pp. 620–625, 2016.

[10] M. Wzorek, “Assessment of leachability of harmful components from alternative fuels prepared with the use of sewage sludge / Ocena wymywalności szkodliwych składników z paliw alternatywnych wytworzonych z osadów ściekowych,” Ecol. Chem. Eng. S, vol. 19, no. 4, pp. 617–627, Nov. 2012.

[11] M. Goňo, M. Kyncl, R. Goňo, and I. Kłosok-Bazan, “Experience with the production of electricity from biogas at sewage treatment plant in the Czech Republic,” Prz. Elektrotechniczny, vol. 89, no. 11, pp. 12–15, 2013.

[12] E. K. Vakkilainen, “Availability and Reliability,” in Steam Generation from Biomass, Elsevier, 2017, pp. 180–202.

[13] C. Cherchi, M. Kesaano, M. Badruzzaman, K. Schwab, and J. G. Jacangelo, “Municipal reclaimed water for multi-purpose applications in the power sector: A review,” J. Environ. Manage., vol. 236, pp. 561–570, Apr. 2019.

[14] D. Sąkol-Sikora, “Problemy związane z zaopatrzeniem w wodę i odprowadzaniem ścieków przez zakłady energetyki zawodowej na terenie Regionu Wodnego Małej Wisły i Górnej Odry,” PKE S.A.

[15] A. Vinogradov et al., “Analysis of the Power Supply Restoration Time after Failures in Power Transmission Lines,” Energies, vol. 13, no. 11, p. 2736, May 2020.

[16] R. Briš, P. Byczanski, R. Goňo, and S. Rusek, “Discrete maintenance optimization of complex multi-component systems,” Reliab. Eng. Syst. Saf., vol. 168, pp. 80–89, Dec. 2017.

[17] E. Podgórni, J. Boguniewicz-Zabłocka, and I. Kłosok-Bazan, “The Impact of Nano-Silver Doses on Microorganism-Deactivation Effectiveness in Water Circulating in a Cooling Tower Cycle,” Polish J. Environ. Stud., vol. 24, pp. 2321–2327, 2015.

[18] J. Krakówka, “Instrukcja eksploatacji Stacji Uzdatniania Wody (SUW) oraz Stacji Demineralizacji Wody (SDW) na potrzeby Elektrowni Opole w zakresie obsługi i kontrolno-pomiarowym.” 2017.

[19] “National Climate Energy Plan 2021-2030 (Krajowy plan na rzecz energii klimatu na lata 2021-2030),” Ministerstwo Energii. Warszawa, 2019