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Impact of Low-Pressure UV Lamp on Swimming Pool Water Quality and Operating Costs

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Abstract: UV lamps are being increasingly used in the treatment of swimming pool water, mainly due to their abilities to disinfect and effectively remove chloramines (combined chlorine). However, the application of UV lamps in a closed loop system, such as that in which swimming pool water is treated, creates conditions under which chlorinated water is then also irradiated with UV. Thus, the advanced oxidation process occurs, which affects the transformation of organic matter and its increased reactivity, and hence the higher usage of chlorine disinfectant. In addition, UV lamps require electrical power and the periodic replacement of filaments. In order to assess whether the application of a low-pressure UV lamp is justified, water quality tests and an analysis of the operating costs (including the energy consumption) of the water treatment system were carried out for two operation variants—those of the low-pressure UV lamp being turned on and off. The experiments were carried out on the real object of the AGH University of Science and Technology sports swimming pool for one year. The consumption of electricity and water treatment reagents was also measured. The following values of the selected parameters of the swimming pool water quality were observed (for without and with UV lamp, respectively): 0.68 and 0.52 mg/L combined chlorine; 3.12 and 3.02 mg/L dissolved organic carbon; 15.70 and 15.26 µg/L trihalomethanes; 7 and 6 cfu/mL mesophilic bacteria; and 6 and 20 cfu/mL psychrophilic bacteria. Generally, the statistically important differences in water quality parameters were not observed, thus the application of the low-pressure UV lamp in the swimming pool water treatment technology did not bring the expected improvement in water quality. However, the higher consumption of electric energy (by 29%) and chlorine disinfectant (by 15%), and the need to periodically replace the lamp filaments significantly increased the operating costs of the water treatment system (by 21%) and its ecological impact, thus this technology cannot be considered as profitable or ecological.

Keywords: swimming pool water; UV radiation; disinfection by-products; energy savings; operating costs

Citation: Włodyka-Bergier, A.; Bergier, T. Impact of Low-Pressure UV Lamp on Swimming Pool Water Quality and Operating Costs. *Energies* **2021**, *14*, 5013. https://doi.org/10.3390/en14165013

Academic Editor: Ioan Sarbu

Received: 19 July 2021
Accepted: 11 August 2021
Published: 16 August 2021

1. Introduction

The widespread understanding of the multiple benefits of swimming has resulted in the emergence of new swimming pools all over the world, as well as in the increase in the number of their users. Swimmers are also having increased expectations regarding water quality and sanitary safety, which is the reason for which the legal requirements and industry standards in terms of the effectiveness of swimming pool water treatment are becoming more and more ambitious. New solutions and technologies have been developed and offered (such as UV lamps, new chemical oxidants and filter materials), leading to the emergence of a separate branch of the industry. It is thus necessary to search for solutions that do not only guarantee proper water quality and swimmers' comfort, but are also energy-efficient, climate-neutral, and with minimal environmental impact. This is further necessary due to the fact that the manufacturers and suppliers of such devices often advertise their solutions as innovative, green and pro-climatic without proper evidence in terms of scientific research and actual results, or even offer devices with high actual energy and material consumption and/or are financially inefficient. An in-depth, scientific approach to the evaluation of the various technological options is necessary, especially due the fact that swimming pool water treatment is a complex and multi-stage process, in which synergies or negative interactions between the treatment stages and reactions often occur.

Swimming pool water is treated in a closed loop—a classic system in which rapid multilayer filters are used (with prior coagulant dosing) and water is disinfected by chlorine compounds (sodium or calcium hypochlorite). In order to improve the quality of swimming pool water, the use of UV lamps is becoming more and more common. Low-pressure (LP) lamps emit UV radiation with a wavelength of 254 nm and MP lamps in the range of 200–400 nm. UV lamps in swimming pool water treatment systems are installed after the filtration process but before chemical disinfection. During irradiation with UV rays, water components are subject to many physical processes (luminescence, photosensitization, heat dispersion) and chemical transformations (particle fragmentation, intramolecular rearrangement, the detachment of the hydrogen atom, dimerization, and electron transfer between molecules) [1]. For typical doses of UV radiation applied during swimming pool water treatment, chlorine photolysis under the influence of UV radiation from both LP and MP UV lamps causes the formation of a large amount of free hydroxyl radicals, therefore the combination of the chlorination and irradiation of water with UV rays is not only an effective method of disinfection but also an advanced oxidation process (AOP). In such a process, free hydroxyl radicals ($HO^{\bullet}$) and chlorine atoms in an excited state ($Cl^{\bullet}$) are formed during the photolysis of free chlorine (HOCl and OCl^{-}), according to the reactions presented in the equations [2–4]:

$$HOCl + UV\ photons \rightarrow HO^{\bullet} + Cl^{\bullet}, \tag{1}$$

$$OCl^{-} + UV\ photons \rightarrow O^{\bullet-} + Cl^{\bullet}, \tag{2}$$

$$O^{\bullet-} + H_2O \rightarrow HO^{\bullet} + OH^{-}. \tag{3}$$

The sequence combination of UV radiation and chlorine (Cl_2/UV) may cause changes in the structure of natural organic matter, causing an increase in the concentration of particles with low molecular weight, an increase in natural organic matter biodegradability, as well as an increase in the ratio of hydrophilic to hydrophobic fractions. Organic matter molecules with high molecular weight become more aliphatic after irradiation with UV rays, as more carboxyl and carbonyl groups appear. Compounds such as low molecular weight carboxylic acids, acetic acids, keto acids and aldehydes were identified in UV-treated water [5,6]. Free radicals generated in AOP processes have very high reaction rates with many substances, particularly with aromatic compounds [1], therefore the content of aromatic compounds is additionally decreased during these processes, and organic matter may be partially mineralized [4,7].

UV radiation (especially UV-C) is one of the most effective disinfectants because it destroys all microorganisms, including *Cryptosporidium parvum*—which is resistant to chlorine. Moreover, the use of UV radiation in combination with chlorination provides multi-barrier disinfection [2,6,8,9]. After irradiating water with UV rays, the share of biodegradable and hydrophilic compounds may increase, and the molecular weight of organic compounds decreases [5,10], which may reduce the biological stability of water [11].

Organic matter is constantly introduced into swimming pool water by swimmers, mainly in the form of sweat but also the epidermis, hair, microorganisms, cosmetics and other personal care products. Additionally, this organic matter reacts with chlorine, which is the most commonly used disinfectant in swimming pools, and disinfection by-products (DBPs) are formed as a result of these reactions. DBPs are undesirable substances and some of them may cause severe adverse health effects [8,9]. The introduction of a UV lamp in swimming pool water treatment technology may affect the dynamics of DBP formation, including their quantity in both swimming pool water and air.

In addition to their disinfecting effect, UV radiation combined with chlorine disinfectants effectively reduce the content of combined chlorine in swimming pool water; however, MP UV lamps are more effective than LP ones in this respect [12–14]. The use of UV lamps may also increase the consumption of free chlorine, due to the fragmentation of organic matter, which reacts more easily and faster with chlorine [13,15] and also to the photolysis of free chlorine under the influence of UV radiation [2,16].

The Cl_2/UV combination, as an advanced oxidation process, affects organic matter in water differently to UV radiation alone. The organic matter, changed by the subsequent chlorination of the water introduced into the swimming pool as described above, may affect DBP formation, including THM. Swimming pool water tests carried out on real objects provide ambiguous results in this regard. Cassan et al. [17], in the experiments with MP UV lamps, observed an increase in the concentration of trichloromethane (TCM) and bromodichloromethane (BDCM) and a decrease in the concentration of dibromochloromethane (DBCM) and tribromomethane (TBM). Kristensen et al. [14], in the studies conducted with the use of LP UV lamps and MP UV lamps, did not observe the influence of the application of UV technology on the change of THM concentration levels; Beyer et al. [18], in the studies of the use of MP UV lamps, noticed a decrease in the total THM, while Afifi and Blatchley [19] observed a decrease in the concentration of THM compounds in water treated with both LP UV lamps and MP UV lamps compared to only chlorinated water. In the studies they conducted on the use of MP UV lamps, Nitter and Svendsen [20] observed higher THM concentration when the lamp was turned on, in both swimming pool water and the air of the room where the pool basin was located. This was due to the fact that THM, as compounds with very high volatility, easily vaporize from swimming pool water. The increase in the concentration of THM and other DBPs in the water is explained by the increased reactivity of organic precursors present in the swimming pool water with chlorine. This reactivity increases after they are exposed to UV radiation and the radicals produced during the Cl_2/UV process [17,20].

Hence, the legitimacy of using UV lamps raises many doubts—even considering their impact on swimming pool water quality. Additionally, these are electrical devices that require a power supply and the replacement of filaments. Moreover, chlorine photolysis and the higher reactivity of transformed organic matter may result in greater chlorine demand. Taking the above aspects into account, the aim of the article was to assess the swimming pool water quality and the operating costs of the system, especially in terms of energy efficiency, with two treatment variants—those of the LP UV lamp turned on and off. The research was carried out on a real facility—the sports swimming pool—during a long-term experiment. The physicochemical parameters of the water quality, disinfection by-products, water microbiological quality, reagent consumption and operating costs, especially electricity consumption, were assessed for the study facility.

2. Materials and Methods

2.1. Study Facility

This research study was carried out for one year, on the real object of the sports swimming pool of the AGH University of Science and Technology (AGH UST) in Kraków, Poland. The volume of this pool is 630 m^3, its water surface area 400 m^2, its length 16 m, its width 5 m and its depth varies from 1.35 m to 1.8 m. The treatment of its water for swimming purposes in the study facility was carried out in a closed loop (coagulant dosing $\rightarrow$ rapid filtration $\rightarrow$ low-pressure UV lamp $\rightarrow$ chlorination with calcium hypochlorite $\rightarrow$ pH correction). A Spectron 150 LP UV radiator by Wedeco was installed in the treatment system, adapted to the maximum flow of 178 m^3/h and the irradiation of water with a minimum dose of 600 J/m^2 and a UV transmission of 95%. The UV dose and all other parameters of this installation were designed according to the size of the swimming pool, particularly in terms of water volume, as well as the flow rate and quality. Spectron units are equipped with UV EcoRay lamps. The radiator consists of 4 filaments, i.e., 4 LP lamps, each with a power of 330 W. Figure 1 shows a technological scheme of the swimming pool water treatment with the location of the UV lamp.

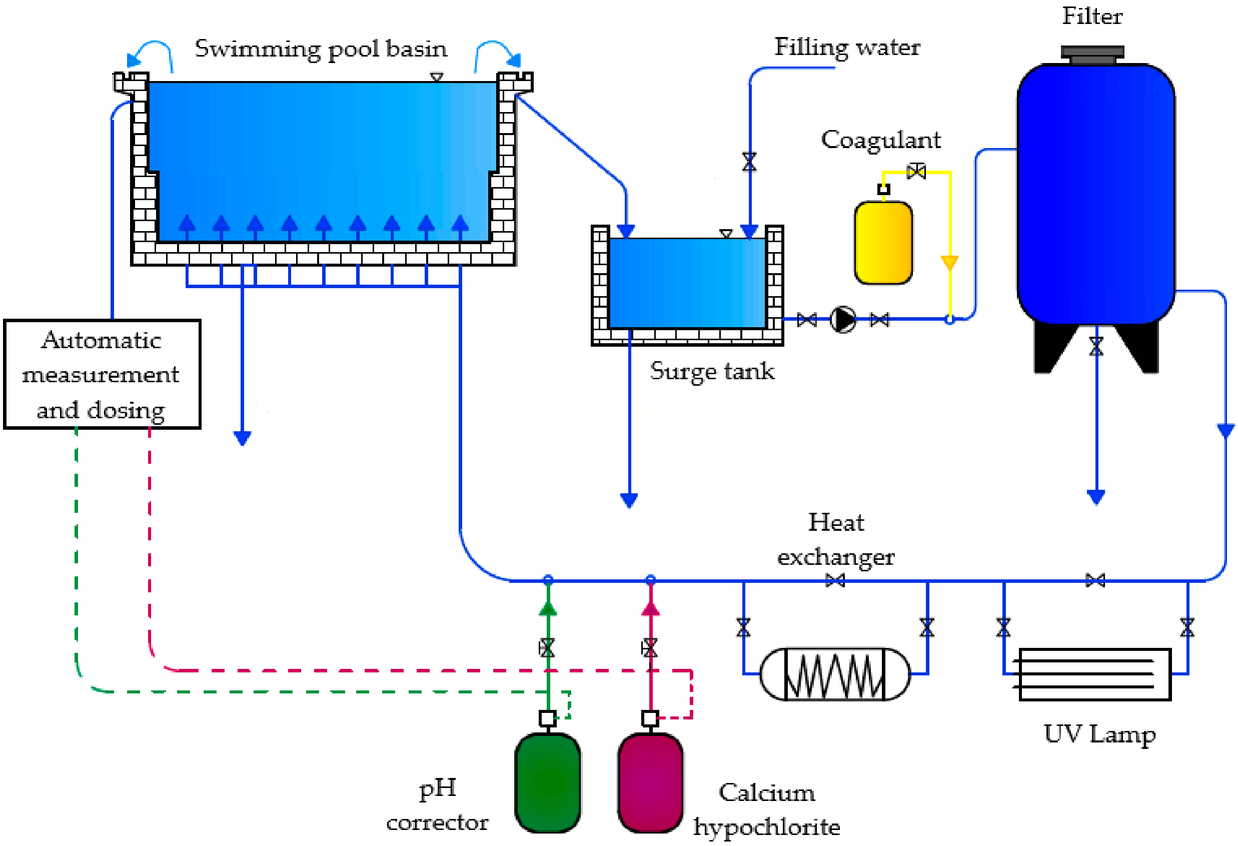

Figure 1. Scheme of the swimming pool water treatment in the study facility, with the localization of the UV lamp.

2.2. Sampling and Data Acquisition

Samples for the analysis of the swimming pool water quality were taken once a week for one year (April to March). The UV lamp installed in the swimming pool water treatment system was turned on for 2 weeks (the variant with the UV lamp) and turned off for 2 weeks (the variant without the UV lamp). The lamp was turned on or off right after the water samples were taken for analysis, so the time of water treatment before the next water sample collection with that disinfection variant was at least 7 days. A total of 37 measurement series were carried out: 18 in the case of the UV–chlorine disinfectant combination and 19 in the case of water disinfection with chlorine alone. The water samples were taken from the sports swimming pool at 2 m from the ladders, at a depth of 30 cm, during the time slot of 10:30–12:00. In the collected samples, several parameters of swimming pool water quality were measured, such as the microbiological parameters (mesophilic and psychrophilic bacteria); THM; the concentration of free and combined chlorine and basic physicochemical parameters, i.e., the bromide concentration, pH, temperature and conductivity, as well as the dissolved organic carbon (DOC) and ultraviolet absorbance (UV_{254}). The specific UV absorbance (SUVA) was calculated as the quotient of DOC and UV_{254}. Both free and combined chlorine were analyzed on site. For the THM analysis, swimming pool water was collected in the dark glass PTFE septum bottles with a dechlorator (ascorbic acid). The bottles were completely filled without any empty space. For the remaining physicochemical analyses, the water was collected separately in bottles with sodium thiosulfate. The swimming pool water samples for the remaining physicochemical analyses were transported to the laboratory and prior to the analyses, they were stored at 4 °C for a maximum of 24 h. On the day of water sampling, the number of swimmers was also counted (from the swimming pool opening to the water sampling).

To estimate the operating costs, the consumption of water treatment agents (calcium hypochlorite, coagulant, pH corrector) and the electricity consumption of the equipment of the study swimming pool water treatment system (circulation pumps, reagent dosing pumps, the UV lamp if switched on) were measured with each change of treatment variant (switching the lamp on or off).

2.3. Analytical Methods and Statistical Analysis

Compounds from the THM group (TCM, BDCM, DBCM, TBM) were determined using the gas chromatograph Trace Ultra DSQII GC-MS by Thermo Scientific. Helium was used as the carrier gas. The separation of the compounds was carried out on a Restek Rxi^{TM}-5 ms capillary column (film thickness 0.5 µm; column length 30 m; internal column diameter 0.25 mm). The analyzed THM were extracted from the water sample with methyl tert-butyl ether (MTBE) by liquid–liquid method according to the methodology recommended by U.S. EPA [21]. The concentration of free and total chlorine was determined by the colorimetric method with N, N-diethylphenylendiamine (DPD), with the UV/VIS spectrophotometer Macherey-Nagel (detection limit 0.03 mg/L). The DOC was determined by the organic carbon analyzer HiPerTOC by Thermo Scientific (detection limit of 0.3 mg/L). Specific UV absorbance (SUVA) was determined as the quotient of the absorbance at 254 nm (measured with the UV–Vis spectrophotometer Aurius 2021 by Cecil Instruments) and the DOC. The concentration of bromides (Br^-) was determined by the spectrophotometric method with chloramine T as the oxidizing agent and phenol red as the indicator. The concentration of bromides was measured with the UV–Vis spectrophotometer Aurius 2021 by Cecil Instruments (detection limit of 0.1 mg/L). The conductivity and pH were measured by electrometric methods using the pH meter CPC-411 by Elmetron and the conductivity meter CC-314 by Elmetron. The total number of mesophilic and psychrophilic bacteria was determined using the pour-plate method with nutrient agar and yeast extract.

For all studied water quality indicators and operating parameters, it was checked whether switching the UV lamp on and off in the swimming pool water treatment technology caused statistically significant differences in the results obtained with both variants. The analysis was performed using the Student's *t*-test in the case of the homogeneity of variance or the Cochran–Cox test in the case of a lack of homogeneity of variance. The equality of variance was tested by the Lavene test, and compliance with the normal distribution was tested by the Shapiro–Wilk test. All analyses were performed using Statistica (ver. 10.0) by StatSoft.

3. Results and Discussion

3.1. Swimming Pool Water Quality

Table 1 shows the average results and the standard deviation of the concentrations of the tested physicochemical and microbiological parameters of the swimming pool water quality for the two variants of the swimming pool water treatment system operation—with and without a UV lamp. Table 1 also includes the number of people using the swimming pool on the measurement day.

The values of the physicochemical parameters (pH, temperature, conductivity, nitrogen compounds, organic carbon) as well as the number of swimmers for both analyzed variants (with the UV lamp on and off) did not show statistically significant differences. However, UV radiation may change the physicochemical parameters of water. It can be noticed that switching on the UV lamp may have a slight effect on the decrease in the concentration of DOC and SUVA, through the partial mineralization of organic compounds, as well as the decrease in the aromatic compounds content [4,7].

Table 1. Average values of swimming pool water quality parameters during water treatment with and without a UV lamp.

Parameter	Concentration (Standard Deviation)	
	Without UV Lamp	**With UV Lamp**
Number of swimmers	158 (69)	155 (65)
Free chlorine, mg/L	0.52 (0.22)	0.49 (0.10)
Combined chlorine, mg/L	0.68 (0.16)	0.52 (0.10)
DOC, mg/L	3.12 (1.26)	3.02 (0.84)
SUVA, $m^{-1}\cdot L/mg$	4.691 (0.958)	1.292 (0.370)
Br^-, mg/L	0.43 (0.02)	0.37 (0.11)
pH	7.28 (0.10)	7.28 (0.09)
Temperature, °C	28 (1)	28 (1)
Conductivity, mS/cm	1.012 (0.226)	0.966 (0.279)
Mesophilic bacteria, cfu [1]/mL	7 (12)	6 (15)
Psychrophilic bacteria, cfu [1]/mL	6 (11)	20 (62)
∑THM, µg/L	15.70 (7.00)	15.26 (5.74)
TCM, µg/L	14.40 (6.10)	14.23 (5.17)
BDCM, µg/L	0.58 (0.67)	0.65 (0.64)
DBCM, µg/L	0.42 (0.71)	0.20 (0.23)
TBM, µg/L	0.31 (0.45)	0.18 (0.23)

[1] cfu—colony forming units.

The water quality in terms of microbiological contamination in the case of both considered variants (with and without UV lamps) did not differ statistically either. The obtained average values of the total number of mesophilic bacteria colonies were very similar for both disinfection variants. The average total number of psychrophilic bacteria colonies was higher with the UV lamp switched on. However, this was due to an incidental case in which a high number of these bacteria was obtained, reaching 281 cfu/mL. A slight increase in the number of heterotrophic bacteria after switching on the LP UV lamp in the swimming pool water treatment system was also reported by other authors [17]. As mentioned in Introduction, the application of UV lamps may decrease the biological stability of water due to an increase in the content of biodegradable organic matter fractions [5,10]. The research study by Pozos et al. [22] of the model water distribution system showed that the application of UV radiation to disinfect water caused the stronger sensitivity of biofilm to the influx of organic compounds (compared to the control, a non-irradiated sample), which is an indicator of secondary microbiological pollution. This was also confirmed by the research of Murphy et al. [11], carried out on the samples disinfected with the UV–chlorine disinfectant combination, which showed that *Escherichia coli* survived in the case of small doses of chlorine, while in the case of chlorination alone it did not. Thus, when using LP UV lamps in a swimming pool water treatment system, the secondary growth of microorganisms may occur more easily, especially with the local deficiency of free chlorine caused by swimmers who enter the swimming pool water. This phenomenon was also confirmed by this study.

Figure 2 shows the average values (with the minimum and maximum) of free and combined chlorine in Figure 2a and of THM in Figure 2b.

In both cases (UV lamp switched on and off), very similar average concentrations of free chlorine in the analyzed water were observed, which actually results from the obligation to maintain the concentration of free chlorine in the swimming pool at the level of 0.3–0.6 mg/L [23]. On the other hand, a statistically significant difference was observed for the concentration of combined chlorine. For the variant with the UV lamp switched off, the increased concentration of combined chlorine was observed in comparison to the results obtained for the variant with the UV lamp switched on. The average concentration of combined chlorine with chlorination alone was 0.68 mg/L, while with the UV lamp switched on the average concentration was 0.52 mg/L (a decrease in the concentration of combined chlorine by almost 24%). Such a situation may result from the fact that the combination of UV radiation and chlorination may lead to the photolysis of a part of combined chlorine [5,17]. UV lamps are commonly used for the dechloramination of swimming pool water; however, MP lamps are more effective than LP lamps in removing combined chlorine compounds [13,14,17,18]. As shown by the results of this research, despite the statistically significant influence of the LP UV lamp on the decrease in the concentration of combined chlorine, the minimum concentration of combined chlorine (0.3 mg/L) required by Polish law was retained [23].

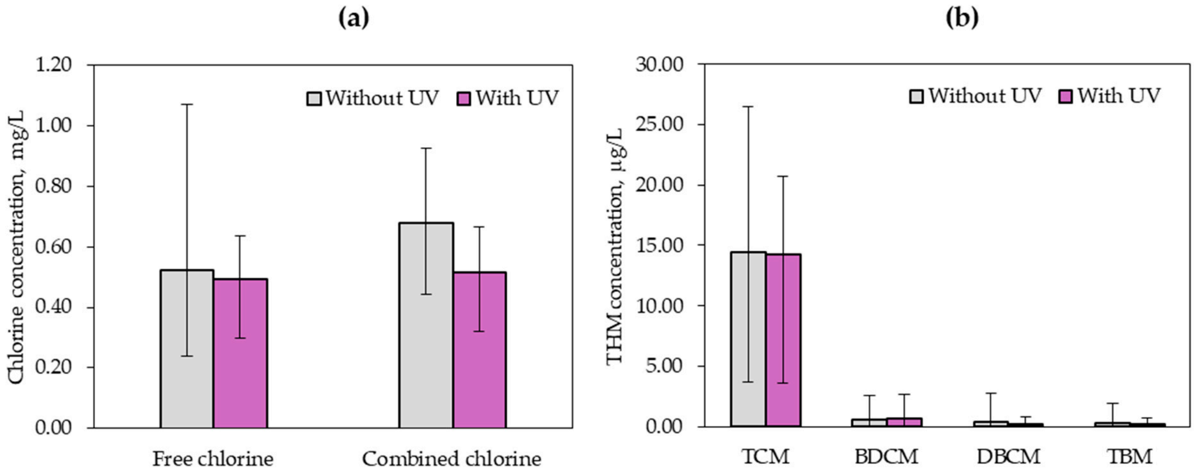

Figure 2. The average values of swimming pool water quality parameters with and without a UV lamp: (**a**) free and combined chlorine; and (**b**) trihalomethanes.

The average concentration of the sum of TCM, BDCM, DBCM, TBM (ΣTHM) was similar in the water samples collected in both disinfection variants, and it was 15.70 µg/L in the case of water chlorination alone and 15.26 µg/L with the UV lamp on (lower by less than 3%). Analyzing the individual compounds from this group, UV radiation applied to disinfect swimming pool water caused a decrease in the concentration of TCM, DBCM and TBM. The average concentration of TCM in swimming pool water treated with the UV–chlorine combination was only 1.2% lower than the concentration of this compound in chlorinated swimming pool water, while in the case of DBCM and TBM, the differences were considerably higher (110% and 72%, respectively). In the case of BDCM, a higher average concentration (by less than 11%) was observed in swimming pool water disinfected in the variant with the UV lamp switched on. For none of the analyzed compounds from the THM group, as well as for ΣTHM, the average concentration obtained in the variant with the UV lamp on and off did not statistically significantly differ. As mentioned in Introduction, there are very few reports in the literature on the influence of UV radiation on the THM content in swimming pool water of real objects, and the results are quite ambiguous [14,17–19]. However, it is known that during AOP Cl_2/UV, the free radicals $HO^{\bullet}$ and $Cl^{\bullet}$ are formed [2,24]. In the opinion of Cassan et al. [17], the increase in the concentration of TCM may be caused by the reactions of these free chlorine radicals, formed during the irradiation of chlorinated water, and organic matter introduced with swimmers, by breaking the C–H bond in organic compounds. The formation of TCM is very quick because the free radicals have very high reaction rates [1]. According to another theory [14], THM formation is influenced by both the degradation of organic matter in reaction with free radicals and the decreasing amount of free chlorine under the influence of photolysis, which may lead to a decrease in the amount of these compounds in the swimming pool water. As shown by the research of Cassan et al. [17], the application of UV radiation in the swimming pool water treatment technology may decrease the amount of DBCM and TBM and increase BDCM. This fact can be explained by the reduction in TBM resulting from its photodegradation [17,25,26]. This may result in the accumulation of TCM and intermediate brominated derivatives such as BDCM [17]. A similar trend was observed in the present study of the AGH UST swimming pool.

3.2. Operating Costs

The alternate and temporary switching on and off of the UV lamp (for two-week periods) made it possible to compare the amount of electricity and chemicals used to treat swimming pool water for the two treatment options. Table 2 summarizes the costs in terms of electricity, the UV filaments and the chemicals used during the analyzed period. Due to the 3.5 h technological break in the treatment system, all daily calculations were made for 21.5 h. The daily costs were converted for the annual period, taking into account the one-month technological break of the swimming pool related to water exchange and maintenance works. Information on the prices of individual reagents and the costs of UV lamps was obtained courtesy of the management team of the AGH UST swimming pool.

Table 2. The operating costs of the water treatment system without and with the low-pressure UV lamp (PLN 1 = EUR ~0.22).

Type of Cost	Operating Costs, PLN/Year	
	Without UV Lamp	**With UV Lamp**
Reagents	35,853	38,455
Electricity	13,359	17,192
Filaments of a UV lamp	-	4031
Total operating costs	49,212	59,678

Chemical agents used to the treat swimming pool water were: a chlorine disinfectant in the form of calcium hypochlorite, a reagent for pH adjustment (50% sulfuric acid—the agent HTH pH minus) and a coagulant (polyaluminium chloride solution, the agent Flockmix Ultra). Figure 3 summarizes the costs of the individual chemical reagents per year of operation of the AGH UST swimming pool.

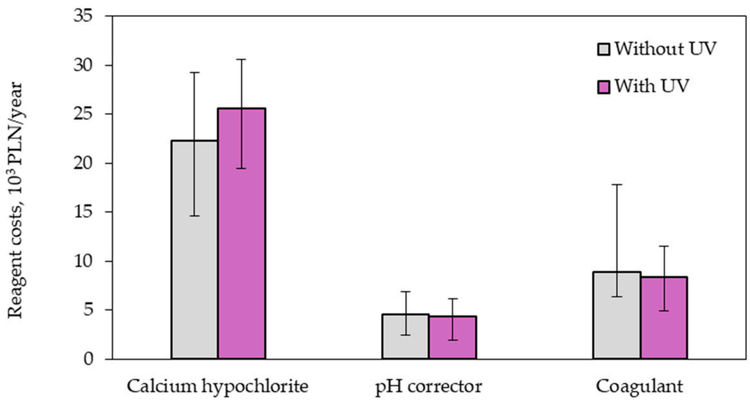

Figure 3. The costs of reagents consumed to treat swimming pool water for the two variants of the installation operation—without and with UV lamp (costs are given in thousands of PLN, PLN 1 = EUR ~0.22).

As can be observed in Figure 3, while the UV lamp was switched on, higher costs of chlorine disinfectant were noted (by PLN 3335.66/year), although this was not a statistically significant difference. The increase in free chlorine consumption may be primarily caused by the increased reactivity of organic matter due to UV radiation [15], the direct photolysis of free chlorine, which leads to the formation of radicals $HO^{•}$ and $Cl^{•}$ may also have contributed to this, however, to a much smaller extent [2,16]. In the case of other reagents, the average costs of their consumption were very similar and amounted to PLN 4615.90/year for the variant without the UV lamp and PLN 4397.75/year for the variant with a UV lamp in the case of a UV corrector; and PLN 8949.19/year and PLN 8433.56/year in the case of the coagulant, respectively. Coagulant is dosed with an electric pump at a fixed dose and the higher consumption of this reagent was probably caused by the incidental increase in the coagulant dose by a pool operator. The pH corrector was dosed automatically, depending on the measurements of the pH-meter and—as can be observed in Figure 3—the application of UV lamp had no effect on the consumption of this reagent.

The UV lamp is an electrical device, so apart from the consumption of chemicals, the electricity meter was checked each time the variant of the water treatment system was changed to measure the consumption of electricity used to power the devices treating the water of the study swimming pool. For the variant with the UV lamp turned on, the costs of powering the devices amounted to PLN 17,192/year and were statistically significantly higher (by 29%) than for the case of the variant without a UV lamp, in which these costs amounted to PLN 13,359/year. For the technology of the sequential combination of UV radiation and chlorination, in addition to the costs related to the purchase of swimming pool chemicals and powering the UV lamps with electricity, it is necessary to include the costs of periodic lamp filament replacement. The UV unit by Wedeco Spectron consists of four filaments, i.e., four LP UV lamps. Therefore, the one-time cost of replacing the filaments for the unit is PLN 6046.32 (the cost of one filament for the lamp used in the analyzed facility is PLN 1511.58). The assumed lifetime of this type of filament is 12,000 h, thus the replacement of filaments in the UV lamp installed at the AGH UST swimming pool took place every 1.5 years on average. Therefore, the annual cost of UV filament replacement is PLN 4030.88.

On average, the total annual cost of operating the water treatment installation for the AGH UST swimming pool with the UV lamp switched on is PLN 59,678/year, while for the variant without the UV lamp, the average cost is lower by PLN 10,466 and amounts to PLN 49,212/year. Adding UV radiation to the swimming pool water disinfection system resulted in generating significantly higher (by 21%) costs related to the operation of the treatment system. The increase in costs was due to the higher consumption of chlorine disinfectant in the form of calcium hypochlorite, the greater consumption of electricity supplying the UV lamp and additional costs related to the periodic replacement of UV lamp filaments. This financial balance only includes operating costs; however, the studied UV installation also required significant capital costs (the cost of the UV lamp itself was PLN 124,500), which further deteriorates its financial profitability, material intensity and generally negative environmental impact.

4. Conclusions

The water quality tests and economic analysis carried out at the AGH UST swimming pool showed that the application of a low-pressure UV lamp in the water treatment technology process did not bring the expected improvement in the swimming pool water quality in terms of the concentration of microbiological parameters, disinfection by-products and combined chlorine. With the simultaneous observed increase in operating costs, this technology should be considered unprofitable. Based on the conducted experiments and their results, the following conclusions were formed:

- Swimming pool water quality in terms of physicochemical parameters and microbiology in the case of both considered variants (with the UV lamp on and off) did not differ statistically.
- A statistically significant difference was noted for the concentration of combined chlorine. The application of the UV lamp decreased the share of combined chlorine; however, the obtained concentration did reach the permissible standards imposed by the Regulation of the Ministry of Health on the requirements for swimming pool water [23].
- The application of a low-pressure UV lamp did not statistically significantly affect the concentration of THM and individual compounds from this group. However, it was observed that UV radiation used to disinfect swimming pool water decreased the concentration of TCM, DBCM and TBM. In the case of BDCM, higher average

concentrations were obtained in the disinfected swimming pool water for the variant with the UV lamp switched on.
- Adding UV radiation to the swimming pool water treatment system can increase the chlorine demand and consequently cause the greater consumption of the chemical chlorinating agent, which increases operating costs.
- The need to power the lamp with electricity and periodically replace filaments in UV lamps additionally increases the costs associated with the operation of the swimming pool water treatment system.

Author Contributions: Conceptualization, A.W.-B. and T.B.; methodology, A.W.-B.; software, T.B.; validation, A.W.-B. and T.B.; formal analysis, A.W.-B.; investigation, A.W.-B.; resources, A.W.-B. and T.B.; data curation, A.W.-B.; writing—original draft preparation, A.W.-B.; writing—review and editing, T.B.; visualization, A.W.-B.; supervision, T.B.; project administration, T.B.; funding acquisition, A.W.-B. and T.B. All authors have read and agreed to the published version of the manuscript.

Funding: The study was conducted within the scope of the AGH UST research no. 11.11.150.008.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments: Management of the AGH UST swimming pool for providing the data and the facility for research.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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