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Sustainable Development in the Context of Hard Water Treatment

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Abstract: The objective of this paper was determination and measurement of the effect on the environment that application of central softening of water from the Grotowice intake can have. In order to carry out the said analyses, two levels of water softening were considered, i.e. up to hardness at the level of 200 $mgCaCO_3/L$ and 250 $mgCaCO_3/L$. For this purpose Grotowice intake collecting water with very high hardness was chosen. Several household appliances which use hot water during their work have been selected for analysis. In addition, the required data were collected and an environmental impact assessment has been prepared (carbon dioxide emissions based on energy consumption of individual appliances, the amount of phosphorus emissions present in used detergents, the amount of waste produced after consumption). As shown by the results of the conducted analyses, limitation of the hardness level of water taken at the Water Treatment Station in Grotowice has a significant effect on reduction of emission of contamination to the environment.

Keywords: sustainable development, hardness of water, environmental impact

JEL codes: Q1, Q5, L23, L31, O31

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1. Introduction

Water characterised with high calcium and magnesium ion content, referred to as hard water, is usually not desired by consumers (Dietrich and Garey, 2015:708-720). This results mainly from the inconvenience related to deposition of scale on heating elements of appliances used in

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households, resulting in higher electricity consumption as well as higher use of cleaning and washing agents, soap and its derivatives used for personal hygiene, which translates into higher emission of contamination into the environment and higher failure rate of household appliances (Hofman ~~at~~ et al. 2007; Kowal and Świderska–Bróż, 2005:539). The range determining admissible water hardness value in Poland is very broad and, despite meeting of the statutory requirements by the water supplied by the water company, the water manufacturers, reacting to the expectations of the customers, have been deciding to employ central water softening systems increasingly frequently. It is common knowledge that the nuisance related to high water hardness occurs at the point of water heating, meanwhile the percentage of water subject to heating in the general balance of water supplied to the consumers is insignificant (Moon et al., 2007:32). Therefore, it is reasonable to ask the question whether application of central water softening is justified, and if so, what environmental advantages will such a solution bring. The attempt to reply to the posed questions was made upon performance of analyses conducted for the research object, i.e. water intake in Grotowice, supplying over 50% of population of the Opole city.

2. Material and methods

The objective of the analysis was determination and measurement of the effect on the environment that application of central softening of water from the Grotowice intake to the level of water classified as medium-hard can have. In order to carry out the said analyses, two levels of water softening were considered, i.e. up to hardness at the level of 200 mg$CaCO_3$/L and 250 mg$CaCO_3$/L. The analyses are based on data collected from the water intake in Grotowice. The values were referred to the annual use of water per person. On the basis of the value of sale and number of residents, it was established for the SUW Grotowice facility that the average annual water intake per recipient is at the level of 101.5 m^3. The sample product was the current situation where the quality of drinking water from the Grotowice intake is characterised with hardness at the level of 400 mg $CaCO_3$/L (Boguniewicz-Zablocka et al. 2016:16)~~.~~. For an average customer of the water supply company, softened water means, first and foremost, less problems resulting from everyday activities of an average household such as washing the dishes, cleaning, washing, boiling water and taking care of personal hygiene. These actions translate into effect on the natural environment arising from use of energy, chemical substances and value of emission to the environment. Attempts to quantify these values were based on calculations of use of electric energy, cleaning agents and level of contamination emission to the environment for the most commonly used household appliances such as: washing machine, kettle, coffee machine. Additional calculations were carried out for agents used in personal hygiene. In case of emission to air, emission of carbon dioxide was analysed as the compound accounting for ca. 80% of greenhouse gases emitted to the atmosphere and the main agent causing global warming. For the purpose of the analysis, data included in the EMAS environmental declaration of the Division of Opole Power Plant for 2015 were used. This facility produces electric and heating energy on the basis of hard coal, and the production capacity is ca. 10.5 MWh annually accounting for ca. 5% of the national electric power demand. In 2014, the carbon dioxide emission to the atmosphere from the Opole Power Plant was 6422 thousand Mg CO_2 with total annual production of electricity at the level of 7,327,100.66 MWh, resulting in 876.48 kg CO_2/MWh (PGE, 2015). Calculation of carbon dioxide emission to the atmosphere resulting from operation of the analysed household appliances was carried out through multiplication of the annual electricity consumption of the given device by the unit emission value specified above. In case of emission to the aquatic environment, the analysis covered emission of phosphorus which is still commonly used in the process of production of washing powders and detergents due to the fact that phosphorus compounds react with ions responsible for water hardness, preventing formation of deposits. Following the provisions of the regulation of the on detailed requirements for certain products due to their negative effect on the environment, stating that *"detergents intended for washing in which the total phosphorus content is equal to or exceeds 0.5 g in the recommended dose of the detergent for the main washing cycle, with a standard charge, for hard water cannot be introduced into trade"*, for the purposes of this paper it was assumed that the total phosphorus content is 0.4 g in the average washing powder dose recommended by the manufacturers. On this basis, the index determining the amount of phosphorus in the average washing powder dose and it was multiplied by the amount of washing powder used within a year by one person.

3. Discussion of analyses results

3.1. Washing machine

The amount of energy used by standard washing machines with power effectiveness class of A ++ ranges, depending on the selected washing program and charge, from 0.46 kWh to 1.02 kWh. In connection with the aforementioned, the average energy consumption was assumed to be 0.74 kWh, and the washing frequency by one person was assumed to once a week. However, energy consumption is also related to the fact of deposition of limescale on the heater installed in the washing machine. Energy consumption increases along with increase of the value of deposits on the heating element, even up to 9% for 1 mm of limescale (Godskensen et al., 2012:85). Use of cleaning agents depends also on the hardness and increases along with increase of the calcium and magnesium compound content in water. Depending on the level of soiling of clothes, the information provided by various manufacturers regarding the necessary dose for washing and water hardness, the amount of the washing powder ranges from 75 g to 166.67 g per single washing. For the purpose of this analysis it was assumed that the load capacity of the washing machine is 4-5 kg, the laundry soiling level is medium and the washing powder dose is the average of the values provided by the manufacturers for the particular water hardness levels, i.e. for soft water - 68.95 g, for medium hard water - 92.06 g, and for hard water - 122.92 g. The above dependencies are presented in table 3.1 for three analysed variants.

Table 3.1. Vitality, energy consumption and washing powder for each variant

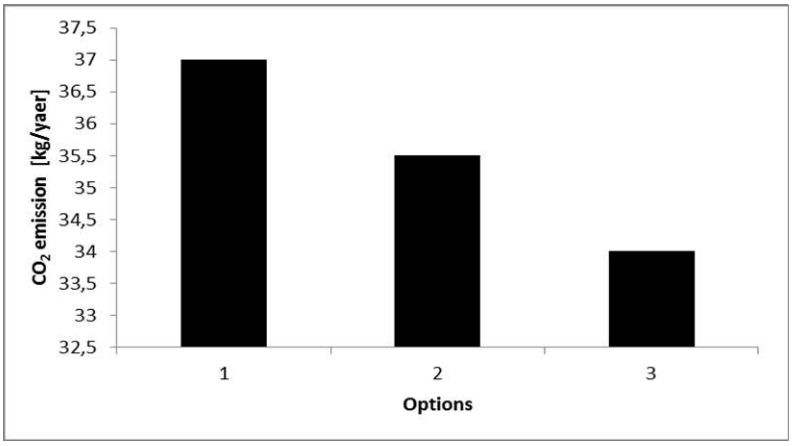
Variant	Vitality [years]	Energy consumption [MJ/year]	Amount of powder [kg / year]
1 - 400 $mgCaCO_3/dm^3$	7	151.83	6.39
2 - 280 $mgCaCO_3/dm^3$	9	145.18	4.79
3 - 160 $mgCaCO_3/dm^3$	12	138.53	3.59

Source: Author's own elaboration

As regards carbon dioxide emission to the atmosphere, the emission resulting from use of the washing machine decreases along with decrease of use of electricity, and this dependence is presented in figure 3.1.1. For variant no. 1, where the water hardness is 400 $mgCaCO_3/L$, CO_2 emission reached the highest level equal to 36.97 $kgCO_2$/year. Whereas, in case of use of soft water, as in variant no. 3, emission of the analysed greenhouse gas decreased to the value of

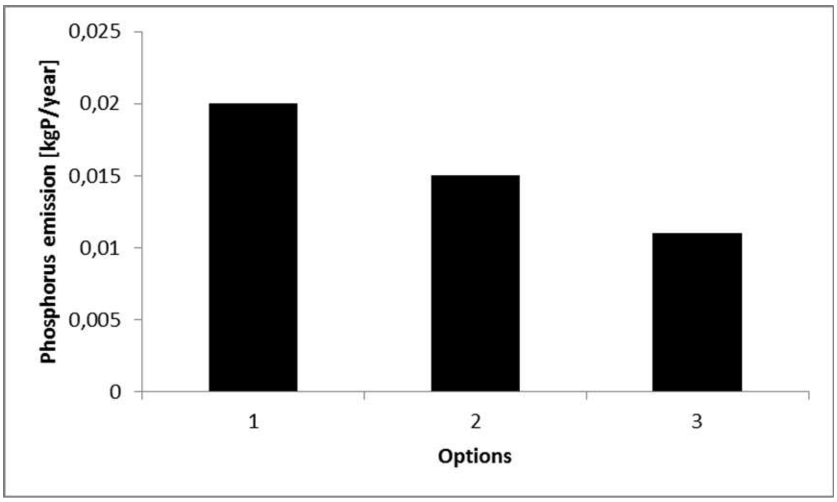
33.73 $kgCO_2$/year. Emission of phosphorus compounds for the analysed variants was as follows: the highest amount of phosphorus compounds, i.e. 0.0208 kgP/year is emitted in case of variant no. 1, characterised with water with hardness equal to 400 $mgCaCO_3$/L. This is related directly to the amount of detergents used for washing. Variant no. 3 is characterised with the lowest emission of phosphorus at the level of 0.0117 kg P/year. The dependence is presented in figure 3.1. 2.

Figure 3.1.1. CO_2 emission for three option of hard water



Source: Author's own elaboration

Figure 3.1. 2. Phosphorus emission for three option of hard water



Source: Author's own elaboration

3.2. Kettle

A kettle is one of the commonly used small household appliances. Currently, the electric kettles are superseding traditional appliances. It was estimated that they are present in all households and one kettle, in a household composed of 2 adults, is turned on three times a day on average. For the purposes of this paper, the analysis covered a kettle with capacity of 1.5 l and power equal to 2200 W. It was measured that boiling 1 l of water in the kettle with assumed power lasts 2 minutes and 20 seconds. Use of electric energy in case of the kettle, similarly to other analysed household appliances, increases along with water hardness increase. It was assumed that in case of variant no. 2, 0.5 mm thick limescale deposited on the heating element, whereas in case of water with hardness of 400 mg $CaCO_3$/L, the kettle heater was covered with 1 mm thick deposit. Similarly to the situations described above, it was assumed that the amount of consumed energy increases by 9% along with increase of deposit on the heating element by 1 mm. In order to ensure proper operation of the electric kettle, the manufacturers of household appliances recommend regular removal of scale. According to data included in the manual of the analysed kettle, for standard use of the kettle, i.e. from 3 to 5 times a day, it is recommended to remove the scale: every 2-3 months in case of soft and medium-hard water (up 306 mg $CaCO_3$/L); every month in case of hard and very hard water (over 306 mg $CaCO_3$/L). The manufacturers recommend vinegar or citric acid solutions for kettle cleaning. For the purpose of this analysis, it was assumed that single-time descaling is performed using 0.5 l of 5% vinegar solutions. For variant no. 1, scale is removed each month, in case of variant no. 2 - every 2 months, and for variant no. 3 - once every 3 months. All calculations were presented as converted into an equivalent unit, i.e. per 1 person, and are presented in table 3.2.

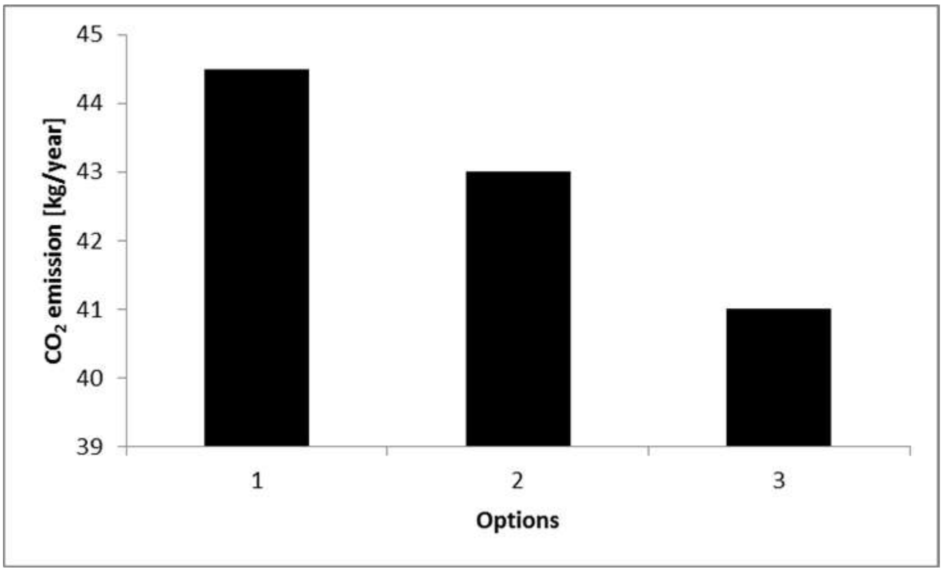
Table 3.2. Vitality, energy consumption and acetic acid for three variants of softening

Variant	Vitality [years]	Energy consumption [MJ/year]	Acid (8%) consumption [L/year]
1 - 400 mg$CaCO_3$/L	5	183.54	3
2 - 280 mg$CaCO_3$/L	7	175.97	1.5
3 - 160 mg$CaCO_3$/L	9	168.39	1

Source: Author’s own elaboration

Use of the electric kettle in households using hard water causes emission at the level of 44.69 kgCO_2/year. The lowest CO_2 emission occurs when using soft water, at the level of 160 mg$CaCO_3$/dm^3, for boiling and it is equal to 41 kgCO_2/year. The dependence of all three analysed variants is presented in figure 3.2.1.

Figure 3.2.1 CO_2 emission for three option of hard water



Source: Author's own elaboration

In case of the kettle, the emission of phosphates to the atmosphere was not provided for, it must be taken into account that there are descaling agents available on the market that contain phosphorus compounds.

3.3. Coffee machine

Over the recent years, the coffee machine has gained popularity among small household appliances. This paper analyses the drip coffee maker with average power of 1000 W. It was assumed that in a household composed of 2 adult persons, the coffee machine is turned on once a day to brew 1 l of coffee which takes 6.5 minutes. Furthermore, these types of devices have a coffee heating function on the heating plate. In such a situation, the machine uses power equal to 55 W, and the heat is maintained for ca. 30 minutes. The amount of consumed energy is, thus, the sum of energy needed to brew coffee and to heat it up on the heating plate. Energy use depends, inter alia, on the hardness of water used for coffee making, therefore, similarly as in case of the kettle, it was assumed that for variant 2 - 0.5 mm thick limescale deposited on the heating element, and for variant no. 1 - 1 mm thick layer. The coffee machine, as any device using hot water for operation, requires removal of scale deposits. Manufacturers of this type of equipment recommend in their manuals to carry out regular descaling, and its frequency depends on the number of cycles or time lapse. It was assumed that in case of hard water, descaling is performed once a month, in variant no. 2 - every 2 months, and in case of hardness of 160 mg $CaCO_3$ – once every 3 months. Most manufacturers of coffee machines recommend use of special descaling agents, without formic acid. It was assumed that 80 ml acetic acid is used for single descaling. All calculated values were divided per person in order to obtain a result in the form of an equivalent unit and specified in **Błąd! Nie można odnaleźć źródła odwołania.**

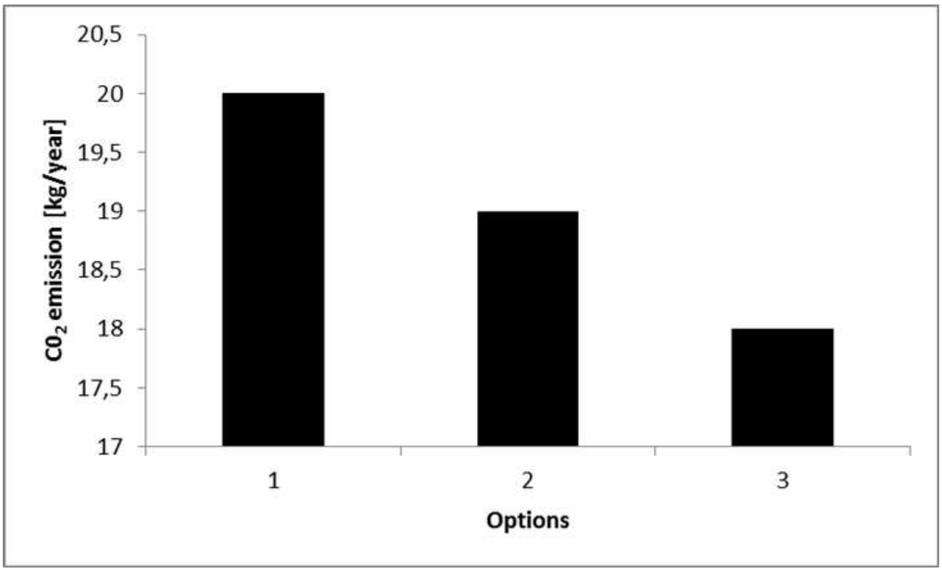
Table 3.3. Vitality, energy consumption and acetic acid for three variants of softening

Variant	Vitality [years]	Energy consumption [MJ/year]	Acid (8%) consumption [L/year]
1 - 400 mg$CaCO_3$/L	5	83.05	0.48
2 - 280 mg$CaCO_3$/L	7	79.62	0.24
3 - 160 mg$CaCO_3$/L	9	76.19	0.16

Source: Author's own elaboration

The coffee machine uses the lowest amount of electric energy, therefore the emission of carbon dioxide resulting from its use is the lowest in comparison to other appliances. The most CO2 - 20.22 kgCO2/year is emitted in case of variant 1, whereas in variant 3, characterised with water hardness at the level of 160 mg$CaCO_3$/L, emission of carbon dioxide is only 18.55 kgCO_2/year. The dependence is presented in figure 3.3.1.

Figure 3.3.1 CO_2 emission for three option of hard water



Source: Author's own elaboration

3.4. Soap use

Data regarding surfactants in the given region, including division into anion and non-anion substances, are difficult to obtain. In connection with the above, in order to estimate the required values, the average statistical data and were used and it was assumed that non-ion compounds account for 25% in the cosmetic products in relation to anion surfactants. According to the data of the Central Statistical Office, the use of soap, surfactants and products used as soap in 2014 was 72.9 thousand tons. Taking the population status as at 31 December 2014 into account, use of cleaning agents per one person is 1.89 kg. In order to the present the dependence of use of soap on hardness of the water used, it was assumed that in case of soft water, the amount of washing agents is 25% lower in relation to the statistical use of soap, taking average water hardness in the country into consideration, i.e. ca. 260 mg$CaCO_3$. The calculations are presented in table 3.4.

Table 3.4 Surfactants consumption for personal hygiene

Variant	Anionic surfactants consumption [kg/year]	Nonionic surfactants consumption [kg/year]	Sum [kg/year]
1 - 400 $mgCaCO_3/L$	1.77	0.59	2.37
2 - 280 $mgCaCO_3/L$	1.42	0.47	1.89
3 - 160 $mgCaCO_3/L$	1.06	0.35	1.42

Source: Author's own elaboration

4. Conclusion

As shown by the results of the conducted analyses, limitation of the hardness level of water taken at the Water Treatment Station in Grotowice has a significant effect on reduction of emission of contamination to the environment. However, it must be remembered that hard water poses a problem mostly during operation of household appliances that heat water and during use of hot usable water. Hot usable water and heated drinking water are only a small part of total water demand in an average household. Undoubtedly, an advantage of hard water is its positive effect on human health (Momeni et al., 2014:160; Ferrandiz et al., 2004:1040; Leurs et al. 2010:414-420). Hard water provides well-absorbable compounds of calcium and magnesium in the diet which, as specified by the WHO, decrease cardiac and nervous system diseases onset rates. Construction of the central reactor for water softening would result in treatment of total amount determined and then distributed to the water consumers. Taking the aforementioned into account, in order to provide an answer to the question whether central water softening is the most beneficial solution in a reliable manner, it is necessary to conduct further analysis that will allow to compare the decrease of negative effect onto the environment in case of use of household water softening stations allowing for treatment of only this part of water that is actually troublesome in terms of use.

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Zrównoważany rozwój w kontekście uzdatniania twardej wody

Streszczenie

Celem analizy było określenie i zmierzenie wpływu na środowisko, jaki może wywrzeć zastosowanie centralnego zmiękczania wody pochodzącej z ujęcia w Grotowicach, do poziomu wody klasyfikowanej jako średnio-twarda. W celu wykonania założonych analiz, w pracy rozpatrzono dwa poziomy zmiękczania wody tj. do twardości na poziomie 200 $mgCaCO_3/dm^3$ i 250 $mgCaCO_3/dm^3$. Analizy oparto na danych pozyskanych z ujęcia wody w Grotowicach. Do analizy wybrano kilka urządzeń gospodarstwa domowego, które wykorzystują ciepłą wodę podczas swojej pracy. Ponadto zebrano wymagane dane i przygotowano ocenę oddziaływania na środowisko (emisje dwutlenku węgla w oparciu o zużycie energii poszczególnych urządzeń, ilość emisji fosforu w używanych detergentach, ilość odpadów powstających po spożyciu). Jak wykazały wyniki przeprowadzonych analiz, ograniczenie poziomu twardości wody pobieranej przez Stację Uzdatniania Wód w Grotowicach może mieć istotny wpływ na redukcję emisji zanieczyszczeń do środowiska.

Słowa kluczowe: zrównoważony rozwój, twardość wody, wpływ na środowisko

Kody JEL: Q1, Q5, L23, L31, O31

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