INŻYNIERIA ROLNICZA
AGRICULTURAL ENGINEERING

2012: Z. 4(140)T.2
S. 165-173

ISSN 1429-7264

Polish Society of Agricultural Engineering
http://www.ptir.org

EFFICIENCY ANALYSIS OF AN AUTOMATIC WATER TREATMENT SYSTEM

Marcin Tomasik, Henryk Juszka, Stanisław Lis
Department of Power Engineering and Automatization of Agricultural Processes
University of Agriculture in Kraków

Summary. The paper presents efficiency analysis of the water treatment controlling system. Introduction sets forth issues concerning this process, various options of its realization depending on the water origin and purpose of its use. Measures were taken within experimental research in the water treatment station and it included: measures of the size of water uptake in pH function, chlorine content and absolute conductivity. Then, correlations between particular examined parameters were determined and necessity of including them in the automatic control process was indicated. Mathematical models in the form of regression equations, which enable optimal performance of the water treatment process were developed.

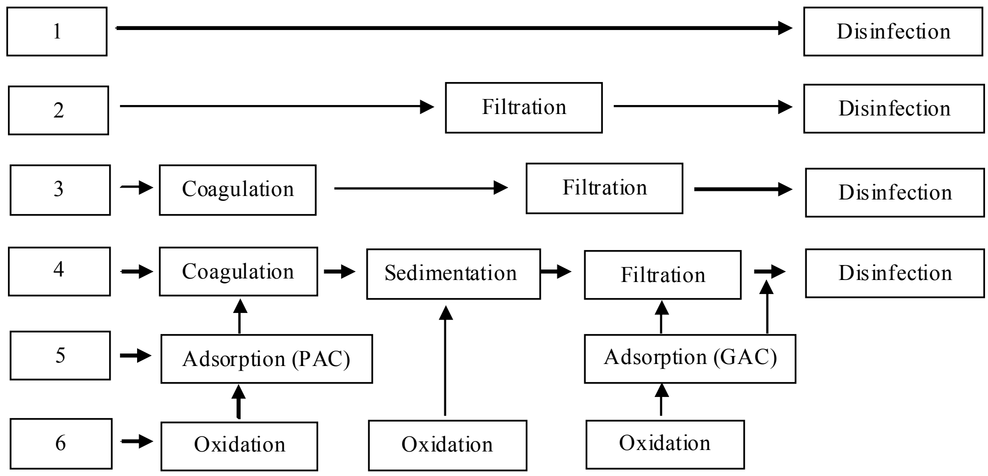
Key words: automatic control, water treatment.

Introduction

Water is the most significant raw material in the world; it includes almost all compounds which occur in the earth's crust. They occur in different concentration depending on their popularity, degree of solubility and many various physical and chemical processes. Water is the best solvent, therefore it is widely used in industry. A considerable part of compounds which can be found in water is natural, the others come from human activity and industry. Exceeded content of iron and manganese, nitrates and ammonia are the most frequent which results from inter alia agricultural activity [Denczew 2002; Górski 2010; Szpindor 1998].

Water treatment process consists in adjusting its physical and chemical properties to requirements resulting from its purpose (fig. 1). Chemical composition of water is the most important factor influencing the water treatment technology. Therefore, before selecting a water treatment method, it is necessary to carry out physical and chemical and microbiological analysis in the laboratory located at the Sanitary-Epidemiological Station. The basic requirement is that water for drinking and consumption purposes should be safe on account of microbiology and chemistry. Water intended for technological processes cannot include corrosive properties nor it can lead to precipitatation of excessive amounts of different types of sediments, which negatively influence the use of a device through deterioration of operation efficiency and even a failure [Denczew 2001; Kwietniewski et al. 1993]. Options of water treatment are selected depending on the pollution degree and the purpose of water use; option 6 is the most advanced. Oxidation process starts, then adsorption method is selected, and sedimentation process occurs – disinfection is the next stage.

The use of automated systems of water treatment enables full control and in effect a safety of this process [Nawrocki, Biłozor 2000].



Source: author's own study based on: Bodzek, Konieczny 2006

PAC – powdered active carbon
GAC – granulated active carbon

Fig. 1. Water treatment methods for life and economic purposes
Rys. 1. Metody uzdatniania wody do celów życiowo- gospodarczych

Pollution occurring in water intakes cause that effective purification and treatment is difficult. Purification technology and a controlling system should be developed individually for a particular type of water on the basis of technological tests. In order to ensure a required drinking water quality, safe for consumers' health and life, using unconventional and high effective treatment processes is necessary despite increase in costs and the need of a very careful and professional exploitation of water treatment. Moreover, inconveniences related to traditional natural waters purification and a changing approach to the concept of water treatment for consumption purposes, mainly increasing quality requirements of drinking water make the application of new separation techniques, possible, among with membrane methods are the most advantageous and are considered as alternative processes [Bodzek, Konieczny 2005].

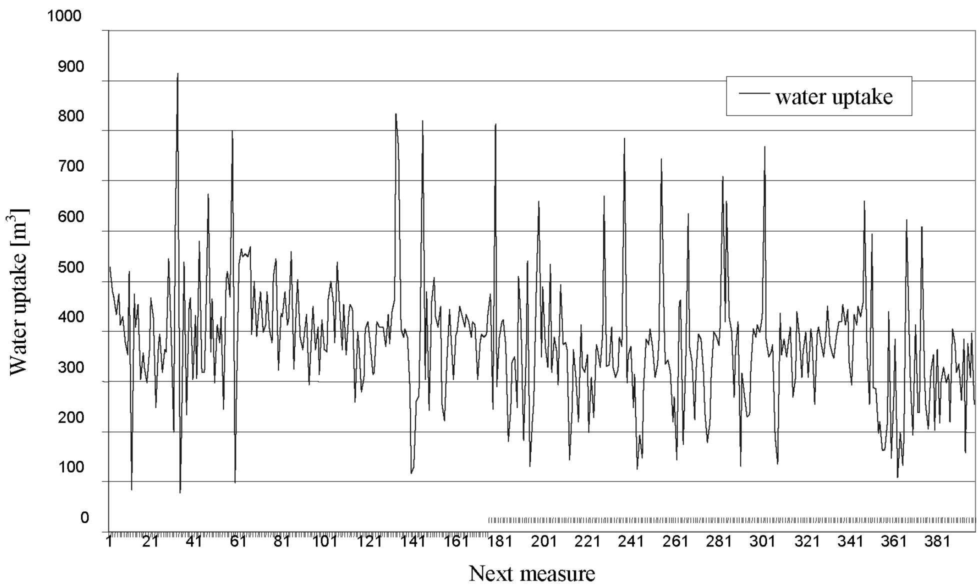
The issue of functioning reliability and safety of water supplying systems is the subject of scientific research in recent years both in Poland as well as around the world. Access to sweet water systematically decreases [Denczew 2002].

The objective of the paper was to analyse the controlling system of the water treatment process. Within the research, experimental research was carried out, which consisted in measurements of: water uptake, pH indicator, chlorine content, absolute conductivity (turbidity). Moreover, analysis of the controlling system along with development of mathematical models of the water treatment process were carried out.

Experimental research

Measurements were carried out in the water treatment station for 30 days from 7. a.m. to 7.30 a.m. Their main purpose was to indicate correlations, significant from the point of view of the process performance, between water parameters and controlling system. On the basis of measurement data regression models were developed, which allows for correction of the controlling system and settings alone. They constitute an important technological information for the researched water treatment station [Lubowiecka et al.1995].

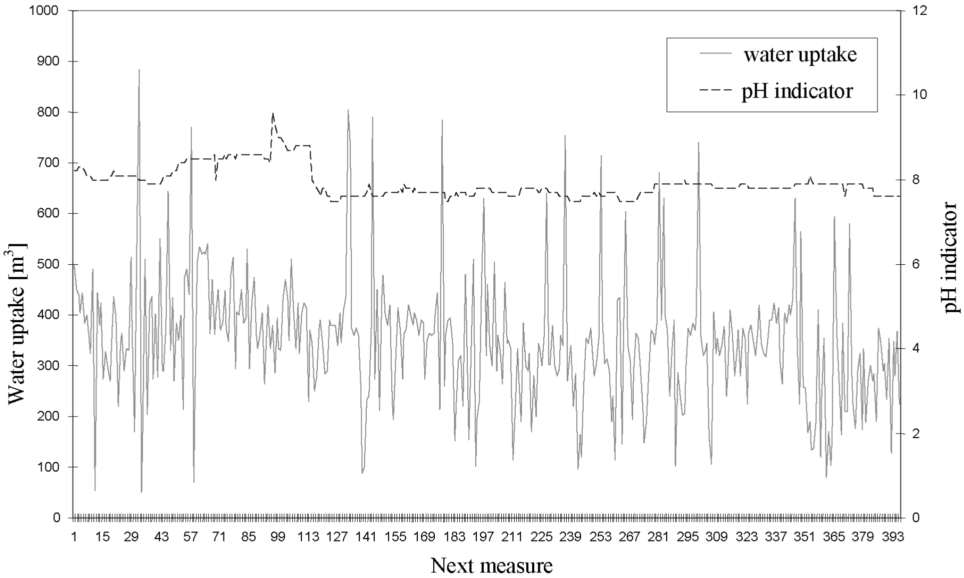
Figure 2 presents characteristic of a daily water uptake from the intake for all measurement series, i.e. 398 measurement days. Average daily value amounted to 347 m^3, a minimum – 50 m^3, maximum – 885 m^3, and standard deviation amounted to 124,65 m^3.



Source: author's own study

Fig. 2. Characteristic of a daily water uptake from intake within 398 days
Rys. 2. Charakterystyka dobowego poboru wody z ujęcia w ciągu 398 dni

One may notice that always after a high increase in water uptake, its sudden decrease occurred. It resulted from the method of using water by citizens. Figure 3 presents a daily water uptake with respective pH indicator. The average value of pH coefficient was 7.92; minimum 7.5; maximum 9.6; standard deviation 0.36. When analysing the obtained results, one may notice that water reaction was always above 7 (7 on the pH scale stands for chemically clear water). Maximum value, which was reported, stands for pH of soap. Visible problems with maintaining pH within a norm, were registered in the first 113 days of reading. The experimental research which was carried out allowed for taking up actions in order to improve this parameter, which is visible in later measurements.

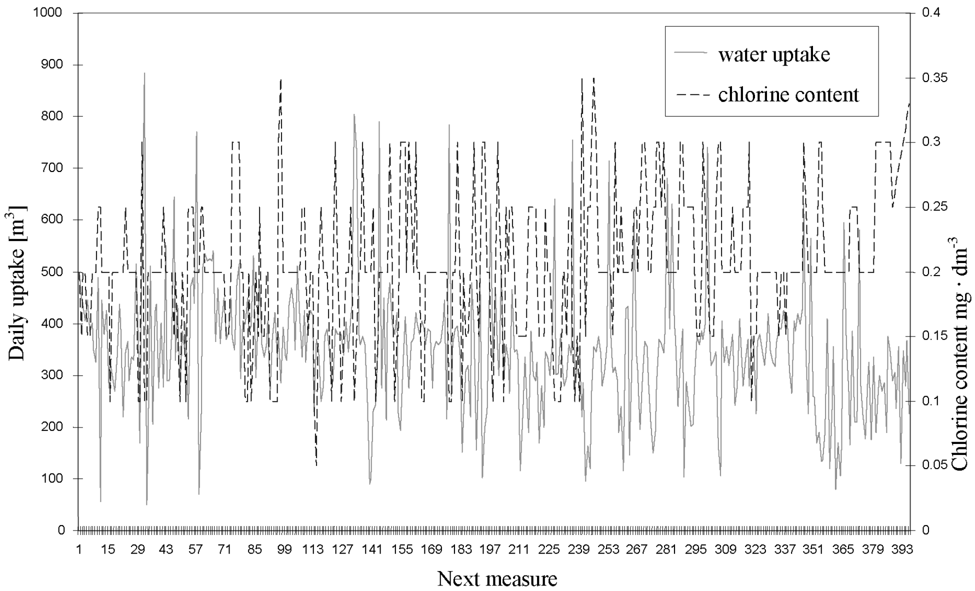


Source: author's own study

Fig. 3. Comparison of a daily water uptake from pH of purified water
Rys. 3. Porównanie dobowego poboru wody z pH uzdatnionej wody

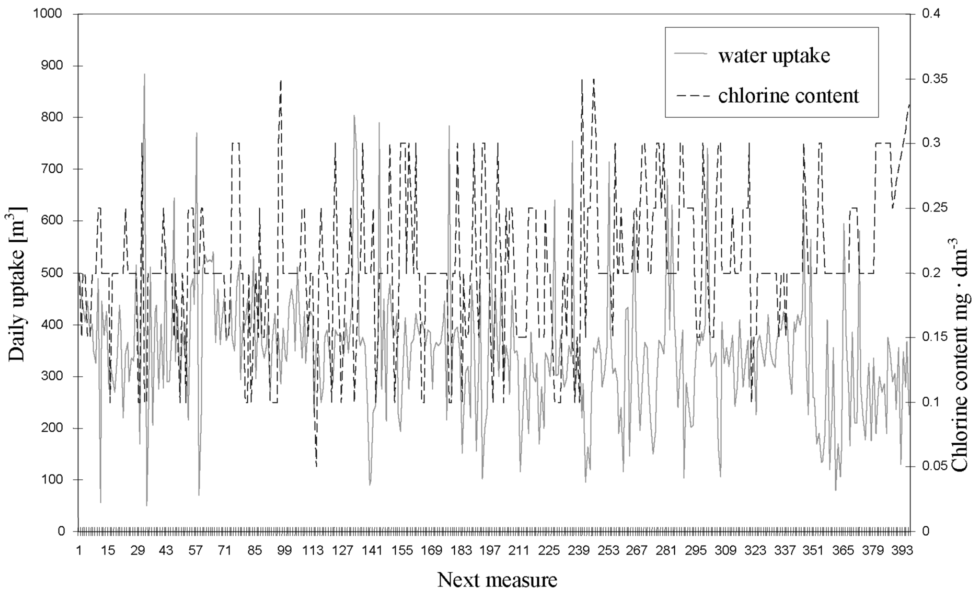
Figure 4 presents relations of a daily water uptake to changes in chloride content in water. The obtained results of measurements confirmed the lack of dependence between water uptake and chlorine content which could have happened. Therefore, necessity of developing a model describing correlation between those two dependencies occurred. This model will be applied in programming of chlorine dosing devices.

Figure 5 presents comparison of absolute electric conductivity expressed in [$\mu S \cdot cm^{-1}$] with a daily uptake. Electric conductivity is a measure of water salinity. The higher is the rate, the more polluted water is. It is accepted that for drinking water it should be within 100□1000 $\mu S \cdot cm^{-1}$ [Cygański 1995; Resolution of the Ministry of Health 2007].



Source: author's own study

Fig. 4. Comparison of a daily water uptake with chlorine content in water
Rys. 4. Porównanie dobowego poboru wody z zawartością chloru w wodzie



Source: author's own study

Fig. 5. Comparison of a daily water uptake with absolute conductivity
Rys. 5. Porównanie dobowego poboru wody z przewodnością bezwzględną

Table 1 presents results of statistical analysis, consisting in determination of correlation between particular, researched water parameters. These correlations allowed indication of significant relations, which should be included in the controlling process. Undoubtedly, the most significant correlation is the one that describes that the increase in daily uptake is not similar to the increase in the amount of dosed chlorine. From the practical point of action, the system of water chlorination, dosing chlorine should depend on the water uptake. Chlorine content in water should be constant.

Table 1. Correlation analysis between the researched parameters of water treatment
Tabela 1. Analiza korelacji pomiędzy badanymi parametrami uzdatnianej wody

Variable	Correlations (water measurements) N=396 (Lack of data were removed with cases) *Marked correlation coefficients are significant with p < 0.05000					
	Average	St. Dev.	daily uptake	pH	chlorine	conductivity
daily uptake	347.0202	124.6475	1.000000	0.175500*	-0.154003*	0.074595
pH	7.9215	0.3616	0.175500*	1.000000	-0.108351*	0.214087*
chlorine	0.2065	0.0551	-0.154003*	-0.108351*	1.000000	-0.024774
conductivity	188.8056	109.0104	0.074595	0.214087*	-0.024774	1.000000

Source: author's own study

Analysis of the water treatment controlling system

Ensuring stable parameters of water supplied to households and industry is a significant task of the water treatment station. On the basis of analysis of such variables flow as pH indicator, chlorine content, water electric conductivity one may notice problems in realisation of supplying this raw material of the required parameters. Therefore, it seems to be significant to determine relation between the discussed parameters, which constitute dependent and independent variables represented by a daily water uptake and absolute electric conductivity and in the next stage describing the discussed relations with proper models allowing for determination of influence of independent variables on dependent variables. Thus, linear models of changes course of acid-base indicator pH and chlorine content in water were formulated, using the above-mentioned factors determining dependent variables (absolute conductivity and daily water uptake) in these models [Wieczysty 1990].

Models were built with the use of forward stepwise regression. In this method, independent variables (describing forecast value) are placed in each step in equation regression and assessed and then left or removed from the equation depending on the assessment. Three linear models describing changes of acid-base indicator pH and chlorine content in water were formulated.

When analysing correlation matrix (table 1) one may notice that increase of demand for water is accompanied by the decrease of chlorine content (negative correlation coefficient); it means that controlling dosing of chlorine is inprecise, therefore it is necessary to develop a model describing relations between water uptake and chlorine content in it. Such model would allow to estimate the course of chlorine dosing depending on the water uptake.

$$ch = \alpha_1 - \alpha_2 d_p + \varepsilon \qquad (1)$$

where:

ch – chlorine content [$mg \cdot dm^{-3}$],
d_p – daily water uptake [m^3],
α_1, α_2 – structural coefficients
ε – random factor.

After models estimation the following form was obtained:

$$ch = 0{,}23 - 0{,}00006 d_p \qquad (2)$$

On the basis of the developed model (formulas 1 and 2) one may say that along with the increase in daily water uptake d_p decrease in the chlorine content will occur by 0.00006 [$mg \cdot dm^{-3}$].

Lack of stability of the acid-base indicator pH is another reported issue. Matrix correlation analysis proves that its value is significantly related to such variables as: absolute electric conductivity and daily water uptake, therefore regression models were formualted which include relations between those variables:

$$pH = \alpha_1 + \alpha_2 p_b + \alpha_3 d_p + \varepsilon \qquad (3)$$

$$pH = \alpha_1 + \alpha_2 p_b + \varepsilon \qquad (4)$$

where:

pH – acid-base indicator
p_b – absolute electric conductivity [$\mu S \cdot cm^{-1}$],
d_p – daily water uptake [m^3],
$\alpha_1, \alpha_2\ \alpha_3$ – structural coefficients
ε – random factor.

After models estimation the following form was obtained:

$$pH = 7{,}63 + 0{,}0007 p_b + 0{,}0004 d_p \qquad (5)$$

$$pH = 7{,}78 + 0{,}0007 p_b \qquad (6)$$

On the basis of the first model (relations 3 and 4), one may say that increase in absolute electric conductivity p_b by 1 [$\mu S \cdot cm^{-1}$] will be accompanied by the increase of pH indicator by 0.0007 assuming that a daily water uptake does not change. While, if a daily water uptake d_p, at maintenance of stable value p_b, rises by 1 m^3 then pH index will increase by 0.0004. These values mean that pH indicator strongly depends on absolute electric conductivity *pb* and slightly depends on a daily water uptake d_p.

In case of the second model (formulas 5 and 6) regression coefficient at the variable p_b means that a unit increase of value of this variable will cause increase of the pH indicator value by 0.0007.

Conclusions

1. Analysis of operation of the water treatment station proved irrational water chlorination. Although, admissible norms were not exceeded, quality of water from the researched uptake was varied.
2. Both, exceed of chlorine in water as well as its lack cause decrease of water quality; then it is characterised by bad smell of chlorine or its short durability, thus the use of formulas (1) and (2) are suggested for programming in an automatic chlorine dosing system. Application of these relations should result in obtaining fixed content of chlorine in water.
3. The statistical analysis, which was carried out proves that introduction of rational water chlorination should influence stabilization of pH indicator in water.

Bibliography

Bodzek M., Konieczny, K. (2005): Ultrafiltracja wspomagana koagulacja jako nowa metoda uzdatniania wody do picia i na potrzeby gospodarcze. Chemia i Inżynieria Ekologiczna, 12(3), 67-81.

Bodzek M., Konieczny K. (2006): Procesy membranowe w uzdatnianiu wody. Inżynieria i Ochrona Środowiska, 9(2), 129-159.

Cygański A. (1995): Metody elektroanalityczne. WNT, Warszawa, ISBN 83-204-1876-3 10.

Denczew S. (2001): Podwójny aspekt bezpieczeństwa w układach dystrybucji wody. II Ogólnopolska Konferencja Naukowo-Techniczna pt.: „Bezpieczeństwo, niezawodność, diagnostyka urządzeń i systemów gazowych, wodociągowych, kanalizacyjnych, grzewczych" Zakopane-Kościelisko. PZiTS Kraków.

Denczew S. (2002): O bezpieczeństwie systemów zaopatrzenia w wodę w świetle ostatnich wydarzeń na świecie. Gospodarka Wodna, 3, 25-28.

Górski J. (2010): Jakość wód podziemnych i jej zmiany w warunkach eksploatacji ujęć. Technologia wody. Wyd. Seidel-Przywecki, (2), 10-14.

Kwietniewski M., Roman M., Kłoss-Trębaczkiewicz H. (1993): Niezawodność wodociągów i kanalizacji. Wyd. Arkady, Warszawa, ISBN 83-213-3638-8.

Lubowiecka T. Wieczysty A. Bednarczyk T. (1995): O potrzebie wprowadzenia probabilistycznych metod badania i projektowania systemów zaopatrzenia w wodę. Konferencja Naukowo-Techniczna pt.: „Aktualne problemy badawcze, projektowe i eksploatacyjne wodociągów i kanalizacji". Wydawca Przedsiębiorstwo INSTAL-compakt Sp. z o.o. Kraków.

Nawrocki J., Biłozor S. (2000): Uzdatnianie wody, Wyd. PWN, Warszawa, ISBN 83-01-13207-8.

Szpindor A. (1998): Zaopatrzenie w wodę i kanalizacja wsi. Ochrona Środowiska, 6, 33-40.

Wieczysty A. (1990): Niezawodność systemów wodociągowych i kanalizacyjnych. T.1. Teoria niezawodności i jej zastosowanie. Cz. I. Skrypt dla przedmiotu: Optymalizacja systemów zaopatrzenia w wodę i usuwania ścieków. Wydawnictwo PK, Kraków, ISBN 62-192-3628-6.

Rozporządzenie Ministra Zdrowia z dnia 29 marca 2007 roku w sprawie wymagań dotyczących jakości wody przeznaczonej do spożycia przez ludzi. Dz. U. z 2007 r. nr 61, poz. 417.

ANALIZA SKUTECZNOŚCI DZIAŁANIA AUTOMATYCZNEGO SYSTEMU UZDATNIANIA WODY

Streszczenie. Przedstawiono analizę skuteczności systemu sterowania procesem uzdatniania wody. We wstępie wskazano na problematykę tego procesu, przedstawiono różne warianty jego realizacji w zależności od pochodzenia i przeznaczenia wody. W ramach badań doświadczalnych wykonano pomiary w stacji uzdatniania wody, na które składały się pomiary: wielkości poboru wody w funkcji pH, zawartości chloru, przewodności bezwzględnej. Następnie określono korelacje pomiędzy poszczególnymi badanymi parametrami i wskazano konieczność uwzględnienia ich w procesie automatycznego sterowania. Na podstawie analizy opracowano modele matematyczne w formie równań regresji, umożliwiające optymalne prowadzenie procesu uzdatniania wody.

Słowa kluczowe: automatyczne sterowanie, uzdatnianie wody

Contact address
Marcin Tomasik; e-mail: Marcin.Tomasik@ur.krakow.pl
Katedra Energetyki i Automatyzacji Procesów Rolniczych
Uniwersytet Rolniczy w Krakowie
ul. Balicka 116B
30-149 Kraków