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Original Research

Mathematical Modelling for Optimizing the Electro-Flotation Process of Water Treatment

Anna Antonyová[1]*, Peter Antony[2]

[1]Faculty of Management, University of Prešov in Prešov, Faculty of Management,
Konštantínova 16, 08001 Prešov, Slovak Republic
[2]APmikro, Pavlovičovo námestie 19, 08001 Prešov, Slovak Republic

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Abstract

Nowadays recycling wastewater is a task in progress. New ways of contamination have appeared together with the technology development. Our article deals with the case of wastewater contaminated with dispersed colorants that are used during the decoration of paper boxes for packaging various products. The wastewater treatment is based on the electro-flotation process. The system is fully automatic, with a possibility to set the time interval for the length of electro-flotation in the tank. The set of experimental laboratory work with equipment development is aimed at optimizing the time interval to manage the proper conditions according to the color used for decoration. LEDs are used to monitor the process. The results are analyzed using statistical methods. The optimum time interval of electro-flotation in a tank for the blue color was set at 25 min.

Keywords: wastewater treatment, electroflotation, testing water clarity, optimization, photodiode

Introduction

Purification of water that was contaminated during the production process prior to its discharge into the public sewage network has become a necessity. Several technologies are available, but electroflotation was used to purify the wastewater contaminated by dispersion colorants in a factory during the production of paper boxes as part of packaging technology. Cardboard boxes are decorated using dispersed colorants, which are subsequently washed by a stream of water from individual machine parts. The electroflotation process as such in itself includes several phases. Dirty water is first collected into a waste pit, from which it proceeds in specific quantities as it is pumped into a reservoir where the water is mixed with the acetic acid that is used as an oxidation agent. Such a mixture of the wastewater with the acetic acid is spilled over into the flotation container where electroflotation process is running. This paper deals with the analytical processing of data about the progressive purification of the wastewater during electroflotation to determine the optimal length of the time interval of the process.

There are several methods for monitoring the process of water purification based on specific data obtained by measurement. A project was carried, for instance, by M. Alsahli et al. [1] to understand both the spatial and temporal distributions of water characteristics. Kuwait water clarity was tested using a sea-viewing wide field-of-view sensor. Multisensor satellite data are the basis for monitoring the water quality in [2]. O. Korostynska et al. [3] suggest a multi-sensor real-time water monitoring system for perpetual assessment of wastewater quality regarding the presence of Nitrates and Phosphates. Santos et al. established a classification of water bodies according to the presence of fecal coliforms that in [4] counted as one of the determinants for classification of the quality of water bodies. N. Usali and M. H. Ismail [5] used remote sensing and geographic information system (GIS) in monitoring water

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*e-mail: antonyova@gmail.com

quality. Measurement of turbidity, which is counted as one of the optical water properties, is assessed in [6]. Light is detected according to the color effect using forward or backscatter detection devices. A complex report [7] describes various aspects of water properties, which are modeled according to the measurement results obtained in the use of digital cameras. A scientific article [8] deals with the treatment of water contaminated especially with heavy metals during gold production in South Africa. Precipitation of heavy metals with lime seems to be a suitable remedy. Monitoring water quality in lakes Rotoiti and Rotoehu led Allan M. G. et al. [9] to the prediction to model variability while also using satellite images.

The results of individual monitoring of water quality characteristics are usually used subsequently for their analysis, prediction, and modeling processes in their interactions. Testing the quality of drinking water at the Federal University of Technology in Owerri, Nigeria [10], is subsequently analyzed according to the standards of the World Health Organization. The analyzed qualities regarded physical characteristics, and bacteriological and chemical properties. Reference [11] comprises a report series about water quality for a healthy country project according to the joint initiative of the Australian and Queensland governments. The publication contains a number of scientific research results that are processed in the form of modeling. A. A. Oketola et al. [12] collected the water samples from the river Ogun in Nigeria. The tested qualities of pH, oil, grease, dissolved oxygen, chloride, nitrate, and phosphate were determined and analyzed using the principal component analysis. Wastewater was tested in Qom Province [13] in central Iran for physical, biological, and chemical indicators. The data were analyzed using the Rapid Impact Assessment Method and Entropy Method. Physico-chemical characteristics of the reservoir [14], such as pH, water temperature, transparency, total dissolved solids and hardness, turbidity, chloride, phosphorate, nitrates, and dissolved and biological oxygen demand were studied for future reservoir management.

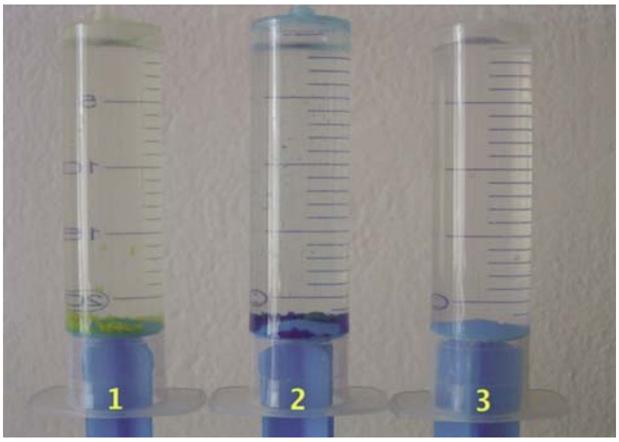

Fig. 1. Standing water in syringes that was already purified by electro flotation after several hours of the self-cleaning process, while: 1) water was originally yellow color, 2) water was originally yellow color, and 3) clear water without any colorants.

Fig. 2. Light green LED on the photodiode in the center front of the tubular cover.

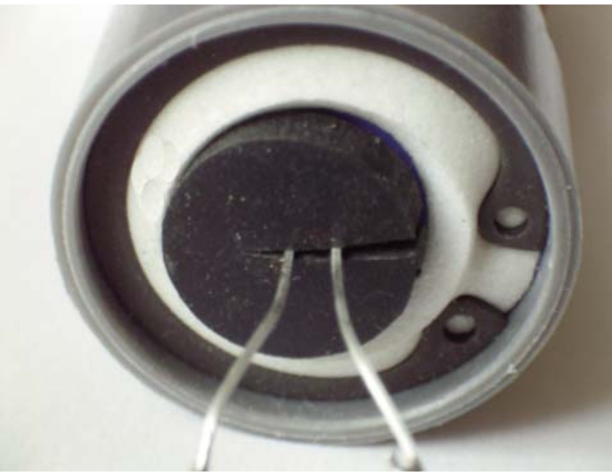

Fig. 3. Sensitive photodiode in the center front of the tubular cover.

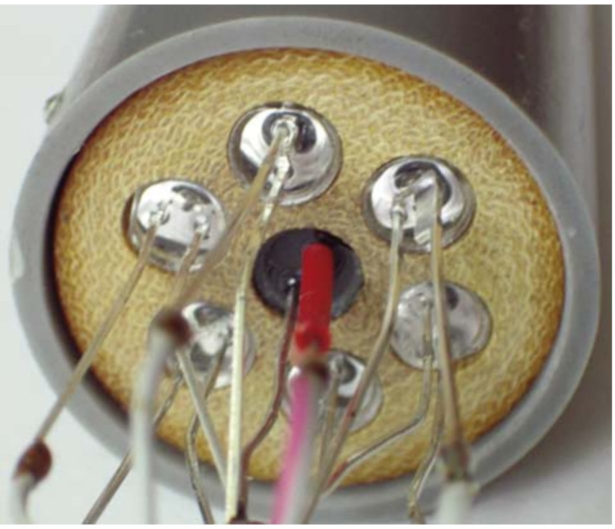

Fig. 4. LEDs on the reverse part of the tubular cover at a length of 140 mm.

Electroflotation tank management in our scientific research work comprises the process optimization. The article follows our publication [15], which was presented in

Bandung and is going to be published on IEEE Xplore. The publication [15] deals with the control process for the automatic electronic system for recycling wastewater. This article presents experimental work on the analysis to model the processes in an electro flotation tank. The publication [16] comprises also detailed comparison of selected turbidity methods.

Experimental Procedures

Electro flotation was conducted in a 1-liter container during all the measurements, while the direct current was set to 250 mA. Two ridge-like stainless steel electrodes are located on the bottom of the container. The electrodes generate tiny bubbles of oxygen and hydrogen. Bubbles capture the disturbed parts of color when floating to the surface, where dirty foam is created. However, the mutual collection of the particulates and foam formation at the surface is made possible by adding a very small amount (1%) of acetic acid into a solution of water with color. This decreases neutral pH 7 to pH 5.5 to allow decomposition of the color solution. As the dirty water is enriched with oxygen during electroflotation process, it has a very beneficial effect on the subsequent purification of water in a standard wastewater treatment plant.

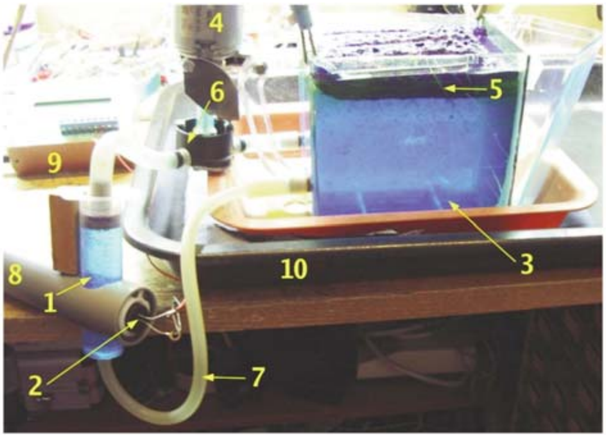

Fig. 5. View of the experimental electro flotation device.

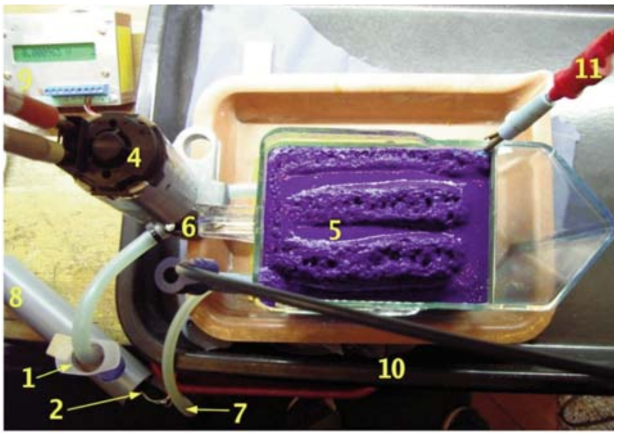

Fig. 6. Electro flotation device with the foam that is formed on the surface, where: 1) 20 ml syringe through which the intensity of the transmitted light is measured, 2) sensitive linear photodiode with protection against external light, 3) stainless steel electrodes on the bottom of the flotator, 4) electric motor of the gear pump, 5) dirty froth as a waste product of the flotation process, 6) gear pump due to the optical measurements of the water during the flotation process, 7) the inlet tube to the syringe of 20 ml, 8) plastic tube cover of the optical measuring device, 9) precise 24-bit A/D converter to measure the voltage of the linear photodiode, 10) protective metal container, and 11) electrical current connection.

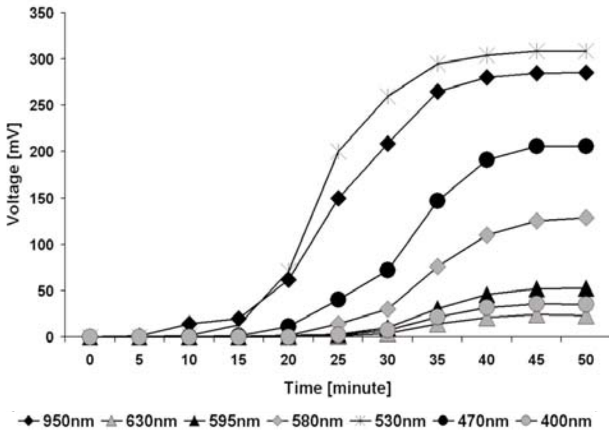

Fig. 7. The voltage at the photodiode receiver for the green color at each of the expressed wavelengths, which are given in nanometers.

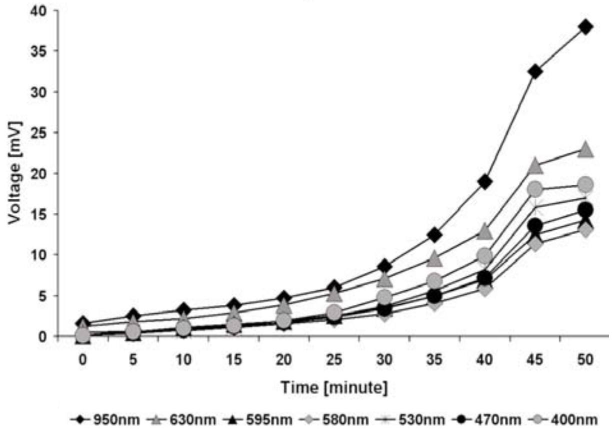

Fig. 8. The voltage at the photodiode receiver for the white color at each of the expressed wavelengths, which are given in nanometers.

Also, the standing water, which was already purified by electro flotation, after several hours, the self-cleaning process occurs there because of oxygen. This is seen in the view of the three 20 ml syringes (Fig. 1), wherein after approximately 48 hours the water is even clearer.

To monitor the level of current water pollution the wavelengths are formed by said LEDs, whose performance is set individually by the trimmers to the same value of the measuring voltage as the receiver photodiode. Specified voltage is measured by a precise 24-bit A/D converter and it is displayed on the LCD after processing. When measuring, the LED light sources are toggled gradually and their light is evaluated. Thus it is possible to evaluate the translucency in the range of seven mentioned wavelengths of light for individual measurements. Measurement was carried out in five minute intervals.

Experimental equipment in details is expressed in Figs. 5 and 6. Some components, such as the LED on the photodiode in the center front of the tubular cover, is expressed in Fig. 2; the sensitive photodiode in the center front of the tubular cover is in Fig. 3; and LEDs on the reverse part of the tubular cover are in Fig. 4.

Results as Modeling with Analytical Approach

The samples of the waste water which were chosen for testing contained dissolved specific color tones of disperse colorants:

- tone 2304 for green
- tone 2401 for white
- tone 2102 for blue

A mixture of wastewater with the colorant particles is placed into the flotation tank. When electro-flotation starts, the cleanness of the wastewater is continuously monitored during the whole process involving the results in writing of every 150s. The measurements were made experimentally in a laboratory while the ambient light was turned off.

The following wavelengths of light are used for measuring purposes:

- 950 nm for infrared
- 630 nm for red
- 595 nm for orange
- 580 nm for yellow
- 530 nm for green
- 470 nm for blue
- 400 nm for ultraviolet

Values were measured in mV for each of the selected wavelengths of light as they was captured with the receiving photodiode while the individual wavelengths are generated by the LEDs. The resulting values of light transmittance in percentage were determined by comparison with the values for the given wavelength for clean water, which represented 100%. This means that the receiving photodi-

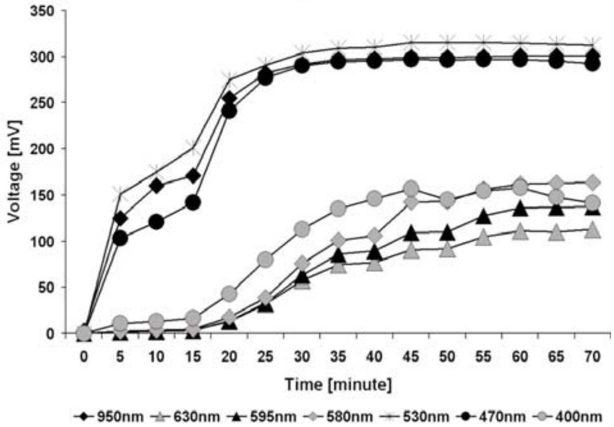

Fig. 9. The voltage at the photodiode receiver for the blue color at each of the expressed wavelengths, given in nanometers.

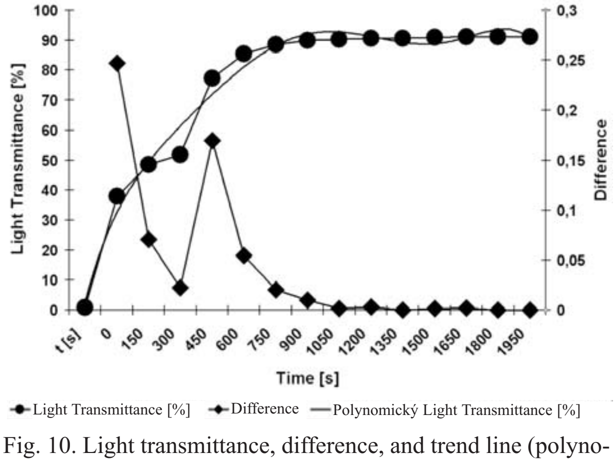

Fig. 10. Light transmittance, difference, and trend line (polynomial) of light transmittance for wavelength of 950 nm while testing blue color.

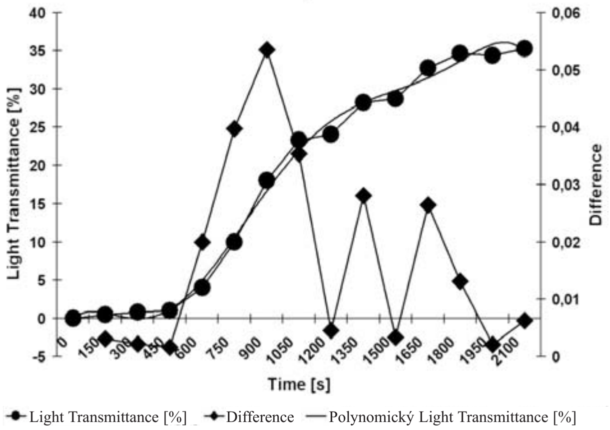

Fig. 11. Light transmittance, difference, and trend line (polynomial) of light transmittance for wavelength of 630 nm while testing blue color.

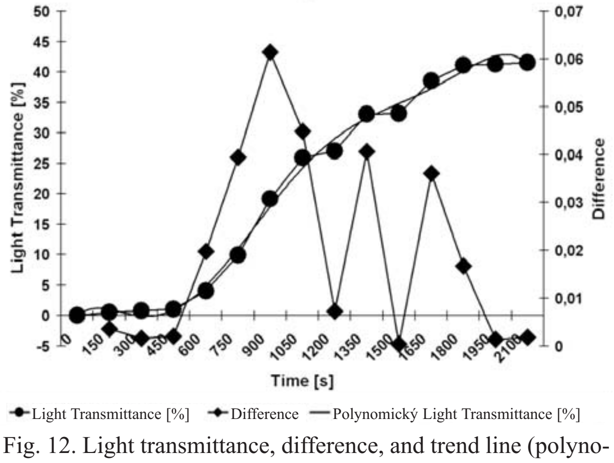

Fig. 12. Light transmittance, difference, and trend line (polynomial) of light transmittance for wavelength of 595 nm while testing blue color.

ode must indicate the same value in mV for each wavelength that is obtained, that is for each transmission LED, namely as the natural pure water in the measurement space.

So modeling the level of the water remedy is expressed as a percentage of the light transmittance as the degree of water purity. Fig. 7 expresses results for green, Fig. 8 for white, and Fig. 9 for blue.

Modeling the level of the water remedy that is expressed in light transmittance in percentage as the degree of water purity is expressed for wastewater contaminated with blue color of disperse colorants in:

- Fig. 10 for wavelength of 950nm, while 330mV expresses 100% as wavelength for clean water
- Fig. 11 for wavelength of 630 nm, while 320 mV expresses 100% as wavelength for clean water
- Fig. 12 for wavelength of 595 nm, while 331 mV expresses 100% as wavelength for clean water
- Fig. 13 for wavelength of 580 nm, while 324 mV expresses 100% as wavelength for clean water
- Fig. 14 for wavelength of 530 nm, while 338 mV expresses 100% as wavelength for clean water

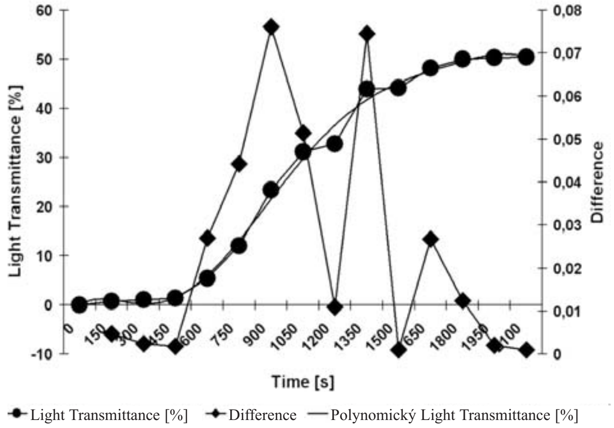

Fig. 13. Light transmittance, difference, and trend line (polynomial) of light transmittance for wavelength of 580 nm while testing blue color.

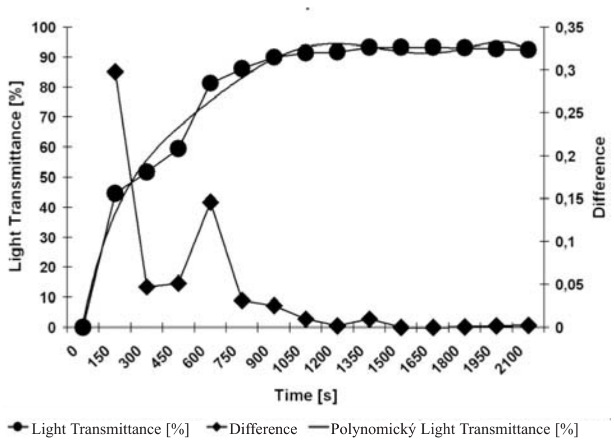

Fig. 14. Light transmittance, difference, and trend line (polynomial) of light transmittance for wavelength of 530 nm while testing blue color.

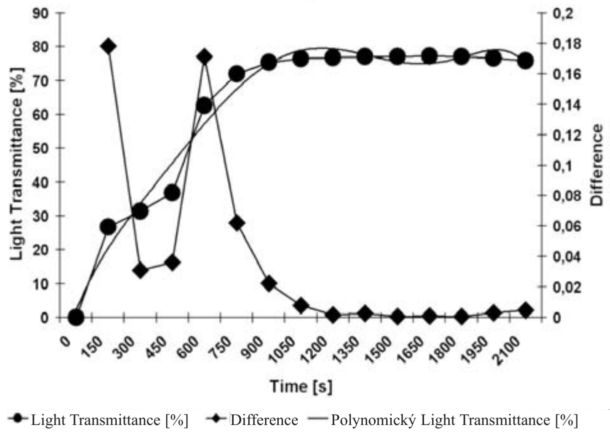

Fig. 15. Light transmittance, difference, and trend line (polynomial) of light transmittance for wavelength of 470 nm while testing blue color.

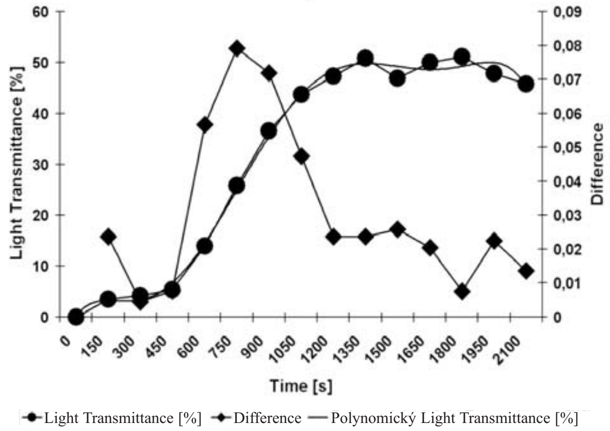

Fig. 16. Light transmittance, difference, and trend line (polynomial) of light transmittance for wavelength of 400 nm while testing blue color.

- Fig. 15 for wavelength of 470 nm, while 385 mV expresses 100% as wavelength for clean water
- Fig. 16 for wavelength of 400 nm, while 309 mV expresses 100% as wavelength for clean water

Difference expressed per 1s in the graphs are given with the formula:

$$Difference = \frac{\left|LT_{n+1} - LT_{n}\right|}{150} \tag{1}$$

...where LT_n expresses light transmittance [%] for the n^{th} measurement.

A trend line to fit the curve, as the graph for the function of light transmittance, was constructed for every given wavelength while testing the wastewater contaminated with the disperse colorant of the blue color. The method of the least squares was applied as a statistical method to fit the curve.

In the following the dependence of light transmittance [%] on the length of the electro-flotation process is proved for the wavelength of 400 nm while testing the wastewater contaminated with blue color.

Table 1. Differences according to formula (1) for 950 nm, 630 nm, and 595 nm wavelengths while testing wastewater contaminated with the disperse colorant of blue color during the electro-flotation process.

Measurement number	Time [s]	Wavelenght [nm]		
		950	630	595
1	0			
2	150	0.246868687	0.0030625	0.003625378
3	300	0.070707071	0.002145833	0.001611279
4	450	0.022222222	0.001666667	0.002014099
5	600	0.16969697	0.02	0.019738167
6	750	0.054545455	0.039791667	0.039476334
7	900	0.02020202	0.053541667	0.06143001
8	1050	0.01010101	0.035416667	0.044914401
9	1200	0.001414141	0.004583333	0.007250755
10	1350	0.003232323	0.028125	0.040684794
11	1500	0	0.003333333	0.00040282
12	1650	0.001414141	0.26458333	0.036052367
13	1800	0.002020202	0.013125	0.016717019
14	1950	0	0.002083333	0.001409869
15	2100	0	0.00625	0.001812689

Hypotheses:

H_0: Light transmittance [%] does not correlate with the length of the electro-flotation process.

H_1: Light transmittance [%] correlates with the length of the electro-flotation process.

The value of Pearson's coefficient for correlation helps us to find the value of the testing characteristics. Pearson's coefficient can be set using the formula:

$$r_{xy} = \frac{\sum_{i=1}^{n} x_i y_i - n\bar{x}.\bar{y}}{\sqrt{\left(\sum_{i=1}^{n} x_i^2 - n\bar{x}^2\right)\left(\sum_{i=1}^{n} y_i^2 - n\bar{y}^2\right)}} \tag{2}$$

...where n = 15, x_i represents the length of the electro-flotation process [s], y_i expresses the value of light transmittance [%].

Thus, $r_{xy} = 0.911258853$

We will compare the value of the testing characteristics with the quintile:

$$\frac{|r_{xy}|\sqrt{n-2}}{\sqrt{1-r_{xy}^2}} > t_{1-\frac{a}{2}}(n-2) \tag{3}$$

The value of the testing characteristics: 7.97794728

The quintile value: $t_{0.975}(13) = 2.16$

Hypothesis H_1 is proved as the values of the testing characteristics and quintile match the relationship (3).

Discussions of Results

This means a correlation between light transmittance [%] and the length of the electro-flotation process [s]. Therefore, we can also express the relationship between light transmittance [%] and the length of the electro-flotation process [s] using the statistical method of the least squares.

For the 950 nm wavelength the polynomial function fit the curve in the following form:

$$\begin{gathered} y = -0.0007x^6 + 0.033x^5 - 0.6159x^4 \\ + 5.6614x^3 - 27.929x^2 + 82.383x - 56.907 \end{gathered} \tag{4}$$

The value for the index of determination:

$R^2 = 0.9812$

For the wavelength of 630 nm:

$$\begin{gathered} y = -0.0004x^6 + 0.0173x^5 - 0.3214x^4 \\ + 2.77x^3 - 10.752x^2 + 17.87x - 9.572 \end{gathered} \tag{5}$$

$R^2 = 0.9947$

For the wavelength of 595 nm:

$$\begin{gathered} y = -0.0004x^6 + 0.0198x^5 - 0.3704x^4 \\ + 3.2454x^3 - 12.938x^2 + 22.154x - 12.18 \end{gathered} \tag{6}$$

$R^2 = 0.9952$

For the wavelength of 580 nm:

$$\begin{gathered} y = -0.0007x^6 + 0.0346x^5 - 0.6732x^4 \\ + 6.5424x^3 - 34.274x^2 + 101.91x - 71.486 \end{gathered} \tag{7}$$

$R^2 = 0.9818$

For the wavelength of 530 nm:

$$\begin{gathered} y = -0.0007x^6 + 0.0346x^5 - 0.6732x^4 \\ + 6.5424x^3 - 34.274x^2 + 101.91x - 71.486 \end{gathered} \tag{8}$$

$R^2 = 0.9818$

For the wavelength of 470 nm:

$$\begin{gathered} y = -0.0006x^6 + 0.0261x^5 - 0.4543x^4 \\ + 3.7397x^3 - 15.941x^2 + 46.229x - 31.61 \end{gathered} \tag{9}$$

$R^2 = 0.9768$

For the wavelength of 400 nm:

$$\begin{gathered} y = -0.0007x^6 + 0.0337x^5 - 0.6201x^4 \\ + 5.2867x^3 - 20.516x^2 + 35.913x - 19.896 \end{gathered} \tag{10}$$

...with the index of determination:

$R^2 = 0.996$

The optimum time interval for the electro-flotation process of wastewater contaminated with blue disperse colorant was set using the results for the differences of the light transmittance between the previous and the following mea-

Table 2. Differences according to the formula (1) for the 580 nm, 530 nm, 470 nm, and 400 nm wavelengths while testing wastewater contaminated with the disperse colorant of blue color during the electro-flotation process.

Measurement number	Time [s]	Wavelength [nm]			
		580	530	470	400
1	0				
2	150	0.00473251	0.297830375	0.178354978	0.02373247
3	300	0.002469136	0.047337278	0.031168831	0.004530744
4	450	0.001851852	0.051282051	0.036363636	0.00776699
5	600	0.026954733	0.145956607	0.171428571	0.056742179
6	750	0.044238683	0.031558185	0.062337662	0.079180151
7	900	0.076131687	0.025641026	0.022510823	0.07184466
8	1050	0.051440329	0.009861933	0.007792208	0.047464941
9	1200	0.01090535	0.001972387	0.001731602	0.02373247
10	1350	0.074485597	0.009861933	0.002597403	0.02373247
11	1500	0.001028807	0	0.000692641	0.025889968
12	1650	0.026748971	0	0.001038961	0.020496224
13	1800	0.012345679	0.000788955	0.000692641	0.007551241
14	1950	0.002057613	0.001775148	0.003116883	0.022437972
15	2100	0.001028807	0.002564103	0.004675325	0.013592233

surements according to formula (1). The results are collected and organized in Table 1 for wavelengths of 950 nm, 630 nm, and 595 nm and in Table 2 for 580 nm, 530 nm, 470 nm, and 400 nm. According to the comparisons we can set time 1500 s, which means 25 min as the optimum time interval. After that interval the mixture of the wastewater starts to be more dirty again.

Conclusions

The specific laboratory equipment was developed to manage the electro-flotation process in the tank. The LEDs are used to monitor the level of wastewater treatment. The set of experimental laboratory measurements were held to control the wastewater treatment process. Intensity values of the transmitted light were displayed for the various wavelengths: 950 nm for infrared, 630 nm for red, 595 nm for orange, 580 nm for yellow, 530 nm for green, 470 nm for blue, and 400 nm for ultraviolet. Specific tested contaminants were represented with green, white, and blue colors. Correlation between light transmittance and length of electro-flotation was proved, which enables us to express the relationships for the treatment process that was monitored for contamination with the blue color of the disperse colorants. Modeling the degree of the water clarification was based on the statistical methods such as least squares. The new method helps us to set the proper time interval for electro-flotation process of the water contaminated with the blue color of the disperse colorants set to 25 min.

In the future we will continue in the research with treatment of the wastewater that is contaminated with some specific colorants such as yellow, brown, and red of disperse colorants, setting the time interval for the length of flotation process running. Another testing will be devoted to purifying wastewater contaminated with oil colorants. These experiments also will require developing the specific equipment and will be a part of our scientific work on the project "Modeling of environmental management processes... ."

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References

1. ALSAHLI M. M. M., PRICE K. P., BUDDEMEIER R., FAUTIN D. G., EGBERT S. Modeling Kuwait Seawater Clarity: A Spatial-Temporal Study Using Remote Sensing And GIS. Applied Remote Sensing Journal. **2,** (2), 17, **2012**.
2. IEEE Xplore Compliant, Catalog Number: CFP1464U-ART [In print].

3. JESMANITAFTI N., JOZI S. A., MONAVARI S. M. Review the Environmental Effects of Using Industrial Wastewater Effluent (Case Study: Iran Qom Shokouhie Industrial State). Journal of Environmental Protection. **5**, 874, **2014**.
4. KOROSTYNSKA O., MASON A., AL-SHAMMA'A A. Monitoring of Nitrates and Phosphates in Wastewater: Current Technologies and Further Challenges. International Journal on Smart Sensing and Intelligent Systems. **5,** (1), 149, **2012**.
5. THIRUPATHAIAH M., SAMATHA CH., SAMMAIAH CH. Analysis of water quality using physico-chemical parameters in lower manair reservoir of Karimnagar district, Andhra Pradesh. International Journal of Environmental Sciences. **3**, (1), 172, **2012**.
6. WEBSTER I. T., BRINKMAN R., PARSLOW J. S., PRANGE J., STEVEN A. DL., WATERHOUSE J. Review and Gap Analysis of Receiving-Water Water Quality Modelling in the Great Barrier Reef. Report to Department of Environment, Water, Heritage and the Arts. National Research FLAGSHIPS. 15 January **2008**.
7. BALASAHEB JAMADAR, PURANDARA B. K. Review on Study of Lake Water Using Multi Sensor Remote Sensing Data. IOSR Journal of Mechanical and Civil Engineering. **6,** (5), 50, **2013**.
8. OKETOLA A. A., ADEKOLUREJO S. M., OSIBANJO O. Water Quality Assessment of River Ogun Using Multivariate Statistical Techniques. Journal of Environmental Protection. **4**, 466, **2013**.
9. ALLAN M. G., HICKS B. J., BRABYN L. Remote Sensing of Water Quality in the Rotorua Lakes. CBER Contract Report 51, The University of Waikato, Hamilton, pp. 1-27, **2007**.
10. MEDEIROS DOS SANTOS G., LOPES-ASSAD M. L. R. C., HOTT M. C., OTENIO M. H. Water Quality and Agricultural Sustainability in the Mantiqueira Ecological Corridor, Brazil. Journal of Environmental Protection. **5**, 500, **2014**.
11. USALI N., ISMAIL M. H. Use of Remote Sensing and GIS in Monitoring Water Quality. Journal of Sustainable Development. **3,** (3), 228, **2010**.
12. OGUEKE CH. C., OWUAMANAM C. I., EZEKIEL J. I. Assessment of drinking water quality within a university community in Owerri, Nigeria. American Journal of Food Science and Nutrition. **1,** (1), 1, **2014**.
13. FEIGHERY L., WHITE M., BOWERS D., KELLY S., O'RIAIN G., BOWYER P. Feasibility study of the use of digital cameras for water quality monitoring in the coastal zone. Maritime Ireland/Wales INTERREG Report 7. Programme- Building Bridges. The Marine Institute, Dublin, pp. 1-32, **2001**.
14. POLLMANN O., VAN RENSBURG L., WILSON F. Optimising the rehabilitation of polluted mine tailings and water by an organic medium passive acid mine drainage treatment in South Africa., Int. J. Environ. Pollut. **41,** (3/4), 336, **2010**.
15. ANTONYOVÁ A., ANTONY P., JOELIANTO E. Optimization the Process of Recycling the Water Contaminated with Dispersion Colorants. TIME-E, Bandung August 19-21, **2014**, Indonesia.
16. ZIEGLER A. C. Issues Related to Use of Turbidity Measurements as a Surrogate for Suspended Sediment. Turbidity and Other Sediment Surrogates Workshop. Reno, NV, pp 1-3, April 30-May 2, **2002**.