Volume : 4 | Issue : 6 | June2015 ISSN - 2250-1991



Research Paper Management

Methods for Modelling the Water Treatment in Environmental Management Study

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ABSTRACT

The contribution presents some mathematical models of the water treatment in the flotation tank. Flotation is one of the methods for clarification the waste water that is specifically contaminated for instance with some oil mixtures or dispersion colorants. The flotation method is highly acceptable for enterprises especially for both its input as well as operating costs. To manage the water recycling, the mathematical modelling might be used to control the flotation process in the tank. The modelling is based on experimental data and uses the methods of statistics, numeric mathematics and differentiation. The proposed models show changes in concentration of impurities in the waste water. The research results are proposed as a part of environmental management study.

KEYWORDS mathematical modelling, water treatment, environmental management

1 Introduction

To keep the life environment imposes high demands on the reverse logistics of each company, as production processes are one of the main polluters in the society. Recycling processes in unity with the development of sustainable sources are promoted also through the state as well as the European Union legislative. Water recycling is carried out in several ways but the flotation method is appropriate especially for its acceptable both input as well as operating costs.

Some details of laboratory testing of the water clarity during the water treatment are described in our article: "Mathematical Modelling for Optimization the Electro-flotation Process of Water Treatment" (Antonyová, & Antony, 2015). The great amount of measurements were carried for the specific colors of the disperse colorants. The photodiode was used to get the values of the light transmittance as the light was passing through the pipe with the water. The individual wavelengths were generated with the LEDs. The measured values were set for each of the selected wavelengths of light as they were captured with the receiving photodiode.

Group of editors: Hermann H. Hahn, Erhard Hoffmann and Hallvard Odegaard (2004) published a set of articles devoted to the methods for chemical waste water treatment from the water desinfection and reuse to the drinking water treatment. Drinking water treatment with the dissolved air flotation model is the main topic also in the next article (Shawwa, & Smith, 2000). Nazih K. Shammas and Lawrence K. Wang (2015) devoted their monograph mostly to the water sources with the related problems.

A computational fluid dynamic model is used for instance to both to investigate the expected negative effects of the wind on the hydraulic as well as to set performance of the tanks with the water and to evaluate the possible suggested improvements (Stamou and Gkesouli, 2015). Scientists Robert Bucki and Peter Suchánek (2012) use mathematical modelling to describe the logistic system trying to control it through a determined heuristic algorithm.

2 Flotation process description

Electro-flotation was used as specific way for the water treatment. During the flotation process, the bubbles are created in the contaminated water. Contaminants are usually some oil mixtures or disperse colorants. Bubbles associated with particles and impurities rise to the water surface together. Thus, foam is formed on the surface of dirty water in the flotation tank. The foam is periodically harvested and exported to a separate processing. The waste water is clarified during the process. The schematic representation of the electro-flotation process, where electrolysis is used for the bubble creation, is expressed in Figure 1, which was designed in collaboration with Ing. Peter. Antony (www.apmicro.com).

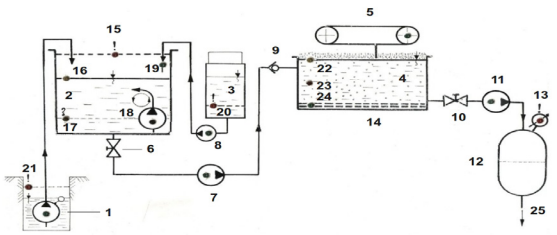

Figure 1. Schematic representation of the electro-flotation process.

Figure 1 shows the schematic representation of the electro-flotation process, where:

1 … tank with contaminated water plus pump for filling of the dirty water into the container in which the contaminated water (number 2) is stirred with acetic acid,
2 … contaminated water pumped into the reservoir plus acetic acid,
3 … storage tank of acetic acid (8%),
4 … contaminated water plus acetic acid in flotation tank,
5 … scraper of the polluted foam that is floated on the surface of the flotation tank,
6 … the outlet valve for pumping up the water to the flotation tank,
7 … the pump for pumping the water into the flotation tank,
8 … a pump with the flow meter for the implementation of acetic acid into the contaminated water,
9 … check valve,
10 … the outlet valve for purified water from the flotation tank,
11 … pump for pumping of the purified water from the flotation tank,
12 … output filter,
13 … overfill alarm of output filter,
14 … flotation tank,

15 … signal overfill (limit level) the container of contaminated water,
16 … the upper level of contaminated water in the tank,
17 … lower level of contaminated water in the tank,
18 … pump for mixing of the contaminated water, which also contains acetic acid,
19 … signaling of filling up with acetic acid,
20 … signaling the minimum level of acetic acid,
21 … signaling overfilling the tank with contaminated water,
22 … sensor and signaling the upper level in the flotation tank,
23 … signaling operation of the flotator,
24 … signaling of passing an electric current through electrodes on the bottom in the flotation tank,
25 … output to discharge purified water into the normal sewage system.

3 Analytical approach with the modelling

3.1 Modelling using the statistical methods

To control the electro-flotation process, the methods of mathematical modelling have been used. The amount of the impurities, which remain in the waste water, was experimentally tested during the electro-flotation process. The modelling tried to use statistical method of the least squares to find out if amount of impurities correlates with the time period of running the flotation process. Table 1 comprises the values for the amount of impurities, which remained in the water after given time period of the running the flotation process.

Table.1. Amount of impurities, which remains in the water after given time period of the running the flotation process.

Flotation [min]	0	15	30	45	60	75
Contaminants [%]	100	39	11	2	1.4	0.9

The following hypotheses were set to describe the process of the water treatment:

Hypotheses setting:

H_0: Amount of the impurities, which remain in the waste water, does not correlate with the time period of running the flotation process.

H_1: Amount of the impurities, which remain in the waste water, correlates with the time period of running the flotation process.

To prove the proper hypothesis we should find the value of Pearson's coefficient for correlation that is given with the formula:

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

where

x_i ... the values of time for the flotation running,

y_i ... the values of contamination in [%].

Thus

r_{xy} = -0.8418741713949430

The value of testing characteristics is compared with the quintile:

$$\frac{|r_{xy}|\sqrt{n-2}}{\sqrt{1-r_{xy}^2}} > t_{1-\frac{\alpha}{2}}(n-2) \quad (2)$$

The value of the testing characteristics:

3.11993678951917

The quintile value:

$$t_{0.975}(4) = 2.776$$

As the value of the testing characteristics is greater than the value of the quintile, the hypothesis H_1 is proved, which means correlation between the amount of impurities, which remain in the waste water and the interval for time period of running the flotation process.

The trend line, that is expressed in Figure 2 shows the exponential dependency between the time period of flotation process and amount of impurities, which remain in the waste water that is given as percentage of contamination. This exponential dependency can be expressed as a relationship that is given with the formula:

$$f(x) = 85.5295713026 * 0.9350817916^{x} \quad (3)$$

With the index of determination:

R^2 = 0.9541201053.

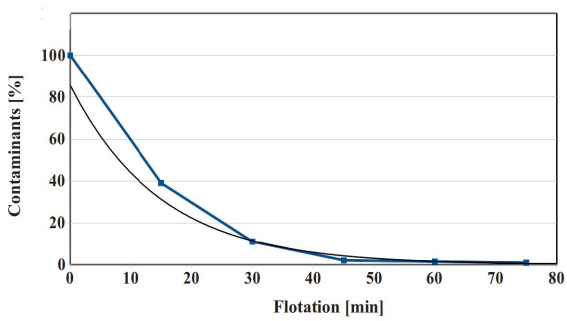

Figure 2. Graphical representation of the dependency between the time period of flotation process and contamination according to the values expressed in Table 1 with the trend line

The proper value of the interval for the flotation process was set to 45 minutes as there is no significant difference between the amounts of contaminants, if the flotation process is running longer.

3.2 Modelling using the method of numeric mathematics

We used Lagrange Interpolating Polynomial as the method of numeric mathematics. The Lagrange Interpolating Polynomial is of the fifth degree and the representing curve directly passes through the given points as they are given in the Table 1. The dependency was aquired using the program system Matlab according to the following system of equations:

$$L_5(x) = \sum_{i=0}^{5} y_i l_i(x) \quad (4)$$

where

$$l_i(x) = \prod_{\substack{j=0 \\ j \neq i}}^{5} \frac{x - x_j}{x_i - x_j} \quad (5)$$

The result with the polynomial expression is written in Semilogarithmic pattern:

$L_5(x)$ = -1.2071e-008x^5 + 4.6091e-006x^4 - 1.0383e-003x^3 + 1.1341e-001x^2 -5.5491e+000x + 1.0000e+002

3.3 Mathematical modelling with the differentiation

Let C [%] represents amount of contaminants in the solution with the waste water, which is placed in the flotation tank. Current content of contaminants in the solution was set as 100%. A solution of the water that is purified to the maximum possible rate with a minimum of contaminants, as it is to be achieved by flotation is marked as 0%. So the problem can be described using the model equation:

$$\frac{dC}{dt} = -k(C - C_z) \quad (6)$$

where k is the coefficient related to the sort of the disperse colorant as a source of contamination.

$C = C(t)$ … level of contamination in % at time t,

C_s ... assumed constant for the maximum possible level of the water treatment using the flotation.

Let both sides of the equation be integrated:

$$\int \frac{dC}{C - C_s} = -\int k dt \quad (7)$$

$$\ln(C - C_s) = -kt + A \quad (8)$$

where A is a constant.

Applying the initial conditions:

$C_0 = 100$ and $C = C_0$ at $t = 0$

$$\ln(C_0 - C_s) = A \quad (9)$$

Hence

$$\ln(C - C_s) - \ln(C_0 - C_s) = -kt \quad (10)$$

$$\ln\left(\frac{C - C_s}{C_0 - C_s}\right) = -kt \quad (11)$$

$$\frac{C - C_s}{C_0 - C_s} = e^{-kt} \quad (12)$$

and so

$$C = C_s + (C_0 - C_s)e^{-kt} \quad (13)$$

$C_s = 0$ for clear water

and applying the boundary conditions:

$$C = 100e^{-kt} \quad (14)$$

Conclusions

In the presented article a few modelling methods were presented to describe the process of the water treatment during the recycling process. We decided to describe the process of the water treatment using the method of electro-flotation that has been proved as one of the most suitable for enterprises with production process that uses some oily mixcure or dispersion colorants. The modelling is important to controll the clarification process in the flotation tank.

The proposed modelling methods are based on the research with measurements leading to the real experimental data aquired during the scientific laboratory experimental work. After the testing we decided for least square method from the field of statistics to describe the correlation between the the time period of flotation process and amount of impurities in the waste water. The exponential dependency was set as the most suitable with the index of determination with the value of 0.9541201053.

Another modelling used numeric method of Lagrange Interpolating Polynomial, which was set as of fifth degree. The polynomial directly describes the curve as it passes through all the given points. The process was described also through the mathematical method using the differentiation.

In our future research we are aiming to deal with the wider variety of the specific contaminants that are used in the production process to control the waste water recycling process.

Acknowledgements

The article was elaborated as a part of the research within the international scientific project 4363-6-14/16 entitled "Modeling of environmental management processes" of the Faculty of Management at the University of Prešov in Prešov, Slovak Republic, and the research institute in Dubna, Federal Republic of Russia.

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