„POLITEHNICA" UNIVERSITY OF TIMIŞOARA
FACULTY OF INDUSTRIAL CHEMISTRY AND
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CONTRIBUTION TO IMPROVING QUALITY INDICATORS OF DRINKING WATER BY USING NEW REAGENTS AND TECHNOLOGIES

Ph. D. Thesis Summary

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CONTENTS

Key words: colloidal suspensions, turbidity, coagulation-flocculation reagent, coagulation-flocculation, Jar-test, optimal coagulant dose, aluminium sulphate, sodium aluminate, polyelectrolytes, backwash water, pilot plant, mathematical model, response time at step signal, perturbations, logical flow chart for optimising

The Ph.D. task was envisaged in 1998 as a way of improving drinking water quality indicators at a waterworks provided with outdated (1950) technology.

From 1998 to 2001, the research consisted mainly in laboratory studies. The existing pilot plant at the waterworks was reshaped from 2000 to 2002 to follow wholly the treatment technology used at the waterworks. Thus, from 2002 to 2003, the research checked the laboratory results and led to working out and checking of the required mathematical models for optimising and automising the waterworks.

In 2003-2004, the results were reflected in approval and execution of the investment for automising and monitoring the Bega River water treatment process, which was based on mathematical models determined by this task. The investment was fully operational in May 2004 and at present the waterworks is monitored accordingly.

Objectives

The major reason for this work was optimising coagulation-flocculation at the waterworks treating the Bega River water for drinking purpose.

The objectives set up for this thesis were as follows:
1. **To review the research in the field of water treatment**
2. **To select the optimal strategy for treating the Bega River water**
3. **Laboratory analyses and studies**
- Analysis of the working conditions for laboratory studies;
- Stages of coagulation-flocculation and set up of the critical stage;
- Simulation of appropriate working conditions for the waterworks;
- Use of new reagents;
- Influence of addition of water with sludge on coagulation-flocculation;
- Determination of "zero" coagulant dose depending on the Bega River water quality;

4. **Studies on the pilot plant. Working out and checking of mathematical models for all stages of the process**
- Study of the dynamic behaviour of the pilot plant;
- Checking of dosing curves by aluminium sulphate;
- Influence of various perturbations on coagulation-flocculation;

5. **Extrapolation and implementation of the obtained mathematical models on the pilot plant to the waterworks**
6. **Working out the logical flow-chart for optimising and automising coagulation-flocculation**
7. **Mathematical processing of experimental results. Working out statistical experimental models**
8. **Interdependence relations among the main variables of the process**
9. **Performance testing of the acquired mathematical models**
10. **Working out final conclusions**
11. **Presentation of the original contributions and directions for research that may be put forth**

Chapter 1 titled „General characteristics of waters for drinking purpose" briefly describes water supply systems, criteria for selecting water sources for drinking purpose, general characteristics of waters, categories and quality standards and usual treatment methods.

Chapter 2 titled „Coagulation in water treatment process for drinking purpose" describes the theory of coagulation-flocculation process and hydrolysis of coagulating agents. The main factors influencing the coagulation-flocculation are also reviewed. The classic objectives to be fulfilled by coagulation-flocculation are as follows:

- Secure minimal turbidity;
- Secure minimal colour;
- Secure final effective disinfection, which is closely related to the values of turbidity and final pH of the treated water;
- Secure good quality flocs;
- Secure optimal final water pH, equal to that of water equilibrium, when calcium carbonate is neither precipitated nor dissolved;
- Secure minimal residual aluminium concentration, which for drinking water must be less than 50 μg/l;
- Secure minimal THM concentration, which for drinking water must be less than 100 μg/l;
- Secure effective coagulation at low temperature.

Chapter 3 titled „Automation and optimisation of water treatment processes for drinking purpose" defines the **concept of automation** for a technological process, which consists in providing facilities with certain special equipment to carry out operation automatically under preset conditions. Another defined concept is **optimisation**, which consists in determining the way and type of action that have to be taken for a given system to get the most favourable qualitative and technical-economic results. In addition, this chapter introduces the mathematical model of a process and required characteristics of a research facility detailing the stages that have to be completed for securing automation.

Chapter 4 titled „Case study concerning automation and optimisation of treatment by chemical reagents", in the introductive part, describes the main elements that make up the base for rehabilitating the existing waterworks. Thus, modernization and optimisation of the existing waterworks suppose:

- Replacement of some of the equipment with other more effective;
- Increase of equipment flexibility, which supposes solid knowledge of the each action and influencing factors, parameters that can be modified and their range of change;
- Addition of new actions;
- Automation of some stages of the technological process;
- Use of new reagents.

The main elements assumed as a basis for rehabilitating the existing waterworks are as follows:

1. Evolution of water quality from the selection and construction of the treatment flux to the moment of rehabilitation;
2. Prognosis of the water quality for the next 20-30 years;
3. Evolution of water demand from the selection and construction of the treatment flux to the moment of rehabilitation;
4. Technological availability;

5. Studies of feasibility taking into account that each water source has its specificity
6. Financial studies
7. Social criteria, which include various elements, starting with the habit of using water and going to the particular elements of each system (source, climate, upstream hydrological basin, age, etc.).

Taking into account the above-mentioned considerations, this thesis proposes to find **optimal solutions** for **improving coagulation-flocculation process** at the Bega River waterworks.

After describing and analysing the existent treatment technology at the Bega River waterworks, two strategies were proposed for optimising the treatment process, namely:
1. Automation of coagulation-flocculation by computer assisted management, -control and -monitoring without major interventions within the existing technology (S1);
2. Automation of coagulation-flocculation by computer assisted management, -control and -monitoring with changes within the existing technology (S2);

The advantage of selecting the first strategy (S1) is that it can be fulfilled on short term, without a major intervention and after that it can be improved by analysing strategy (S2).

Strategy (S2) assumes long term research for selecting more effective reagents taking into account the seasonal variation of the raw water quality, major investment such as replacement of the existing mixers by mechanical ones provided with variable speed stirrers for higher flexibility, replacement of the existing settling tanks by more effective ones or rehabilitation to increase efficiency. The advantage of strategy (S2) is that it can be carried out in parallel with strategy (S1).
The thesis approaches both strategies based on the carried out analyses and studies.
Strategy S2 was approached only for checking the efficiency of using new reagents. In that way, analyses and studies were carried out to use pre-hydrolysed aluminium sulphate prepared in the laboratory, BOPAC (a basic solution of aluminium chloride), anionic polyelectrolytes and backwash waters resulting from the existing technology. However, the need for rapid fulfilment of the main objective led to the priority approach of strategy S1.

Laboratory studies were carried for:
- setting up the conditions for developing of coagulation-flocculation by jar test method, which replicate the conditions at the waterworks to the best;
- setting up the critical stage of the treatment process;
- determining "zero" dose depending on the Bega River water quality, a dose required to calculate aluminium sulphate and sodium aluminate doses when the two reagents are used together. The "zero" dose is the maximum dose of aluminium sulphate for which the optimal pH is secured as a function of the raw water quality.

Other experiments were carried out to study the dynamic behaviour of the pilot plant by using the method of response at step signal, check the dosing curves by aluminium sulphate and determine the influence of various perturbations on coagulation-flocculation.

For the method of response at step signal in the mixing chamber of the pilot plant, the model equation was as follows:

$$Y = a + bX^2 + cX^4$$

where
X – time, min
Y – flow rate, L/s
a, b, c - constants

According to that model, the critical time was of 1.5-3 min and retention time 3.9-7.7 min at 20-50L/s flow rate.

When the reaction chamber and settling tank was considered, the model became

$$Y = a + bX + c/X^2$$

and the critical and retention times were 17-43 and 20-51 min for the reaction chamber, and 1.3-3.7 and 8.6-23.2 h for the settling tank, respectively at 20-50 L/s flow rate.

The chapter concludes by presenting a logical flow chart for automation-optimisation based on the studies described hitherto.

Chapter 5, titled „Mathematical processing of experimental results. Working out statistical experimental models." Among models worked out, one was used to determine the theoretical pH in the reaction chamber at a certain aluminium sulphate dose, which was selected from the coagulation curve, and certain pH of the raw water. Model equation is as follows:

$$pH_t = pH_{rw} - 0.00017 \times D_T^2 - 0.14 \times D_T^{0.5}$$

where:
pH_t – theoretical pH
pH_{rw} – raw water pH
D_T – aluminium sulphate dose

This model can be used for the pilot plant and waterworks at ±0.1 accuracy pH units. By the help of this model, one can rapidly determine the "zero" dose. Another possibility refers to the control of coagulation-flocculation when the optimal pH in reaction chamber must be 7, which is the case of dosing aluminium sulphate and sodium aluminate as a mixture.

All mathematical models that derived from the studies are described and the actual mathematical models valid for the waterworks ~~to automate optimise the~~ coagulation-flocculation process resulted by extrapolation.

Chapter 6, titled „Interdependence relations among the main variables of the process" presents the main interdependence relations among parameters that intervene to determine the appropriate coagulation-flocculation reagents to secure water quality according to the valid standards.

Chapter 7, titled „Performance testing of the acquired mathematical models" describes the performance of the obtained mathematical models both from a statistical point of view by using Jandel Scientific TableCurve 2D v 5.01 software and from a practical one at the waterworks.

Chapter 8 presents the final conclusions as against the proposed objectives, personal contributions of the author and future directions for research.

The original contributions within this thesis refer to:
1. Original approach of assessing the exiting technology at waterworks;
2. Determination of critical stage;
3. Determination of working conditions for coagulation-flocculation by jar test method;
4. Study of the dynamic behaviour of the pilot plant by using the response to step signal to know the dynamic behaviour of the waterworks;
5. Study of the perturbing parameters that influence coagulation-flocculation
6. Working out of the mathematical model to determine the theoretical pH in the reaction chamber at a certain aluminium sulphate dose, which was selected from the coagulation curve, and pH of the Bega River water;
7. Working out and implementation of the logical flow–chart for automating coagulation-flocculation process;
8. Working out of the mathematical model to set up the total dose of aluminium sulphate;
9. Working out of the mathematical model to set up the concentration of aluminium sulphate solution

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