

# The Role of Zeta Potential in the Optimization of Water Treatment

U. Nobbmann\*, A. Morfesis\*, J. Billica\*\* and K. Gertig\*\*

\*Malvern Instruments, 117 Flanders Road, Westborough, MA  
ana.morfesis@malvern.com

\*\*Water Treatment Facility, City of Fort Collins, USA, CO

## ABSTRACT

Drinking water in developed nations of the world is typically treated to remove contamination of foreign materials, both mineral and organic. Contaminants can be present in almost any water source and can be detected in water supplies obtained from mountains, rivers and soil, with even greater contamination potentials coming from domestic sewage and industrial waste.

Zeta potential provides a measurable value to monitor optimal water clarification capabilities. Its value indicates the repulsive interaction between particles; a zero zeta potential means that the conditions for the aggregation of contaminants are maximized. Control charts monitoring the zeta potential of the Fort Collins Water Treatment Facility will be reviewed. Optimal conditions for water production controls can be obtained by monitoring zeta potential, turbidity and flocculating agent concentration.

**Keywords:** zeta potential, drinking water, clarification, flocculation

## 1 INTRODUCTION

Zeta potential has been used in the water treatment industry for many years to help determine coagulant dosages.[1-2] Zeta potential is a measure of the electrical potential between particles, and indicates the repulsive interaction between particles; a zero zeta potential means that the conditions for the aggregation of contaminants are maximized. Dentel[3] provides references to work by others that indicate a variety of zeta potential ranges for optimum contaminant removal, including coagulated waters with ranges of -4 to +3mV, -5 to +5mV and -13 to +13mV. Bench and pilot studies have shown that operating within the zeta potential range of -10 to +5mV can minimize contaminants measured as Total Organic Carbon (TOC) residuals.[3-7] High TOC and particulate levels exert a very strong demand on flocculating agents (alum) in water treatment facilities. Therefore, by monitoring zeta potential the use of flocculating agents may be adjusted for optimal clarification conditions, and narrowing the zeta potential operating controls of any water production facility (in general) must be site specific and must be determined empirically.[8-11]

## 2 EXPERIMENTAL

Fort Collins Water treatment Facility (FCWTF) uses a conventional treatment process, including alum coagulation, flocculation, settling and filtration. Flocculation and settling take place in four parallel trains with design flows to each train of about 20 million gallons per day (MGD). The flocculation portion of each train is characterized by serpentine plug flow with variable speed, horizontal paddle flocculators. A high molecular weight cationic organic polymer is added during flocculation to improve the size, strength and density of the floc. Settling in one of the trains is aided by tube settlers, while settling in the other three trains are aided by lamella plates. A polymer filter is added to the settling basin effluent, prior to filtration by 23 dual media, constant rate filters. [7]

### 2.1 Choice of Flocculant

Alum ( $\text{Al}_2(\text{SO}_4)_3 \cdot 14.3\text{H}_2\text{O}$ , 48.5% by weight solution strength) feed uses a flow paced control. Alum is added at in-line mechanical mixers downstream of a  $\text{CO}_2$  feed point. The in-line mechanical mixers consist of vertically oriented, constant speed impeller type mixers operating within a pipe spool. Each mixer is equipped with dual axial flow impellers to generate a high mixing intensity. The design velocity gradient is  $1,000 \text{ sec}^{-1}$ . In-line mechanical mixers are used at the FCWTF to provide for the near instantaneous mixing of alum that is necessary for the coagulation reaction.[12]

### 2.2 Optimization of Flocculant

The alum dose has historically been selected by the FCWTF operators based on a number of indicators including jar test (sedimentation) results, zeta potential data, streaming current monitors, settled and filter effluent turbidities, settling characteristics of the floc, filter run times, residual aluminum and raw water TOC, color and turbidity.[12]

However, during specific times of the year, because of natural weather conditions, water quality can fluctuate quickly and at these times rapid decisions about coagulant dosages must be made. In such situations, two-hour jar tests conducted in the morning may not be representative of the water that is coming into the plant by afternoon. Therefore

it is the frequent use of zeta potential measurements that provide critical results for determining alum dosage at the FCWTF particularly during times of rapidly changing water conditions.[12] Water production data were measured during each eight hour shift and each train of the Fort Collins Water Treatment Facility (FCWTF) throughout the year 2002.

### 2.3 Zeta Potential: Method to Rapidly Check Flocculant Efficiency

Zeta potential measurements were carried out using either a Zetasizer Nano ZS instrument with MPT-2 automated titrator or a Zetasizer 2000 HSA instrument both manufactured by Malvern Instruments, Ltd. Worcestershire, UK. A typical data acquisition takes only minutes. The method requires very little sample (about 1 ml of water) and is fairly automated in the software, such that a standard operating procedure can be incorporated.

## 3 RESULTS

By studying the concentration of flocculant additive dosage vs. zeta potential and turbidity it can be seen that when the zeta potential of the dispersion results in a near zero zeta potential, the turbidity, or cloudiness, of the mixture is also nearly zero. Analysis of zeta potential vs. coagulant dosage results are used to evaluate the effectiveness of various chemicals (typical examples are alum, ferric sulfate, etc.) and a number of commercial brands of cationic polymers (these usually contain a quaternary ammonium surfactant that imparts the cationic surface charge). Knowledge of zeta potential is important to optimize adjustment of coagulant dosage levels periodically in order to minimize cost of chemicals for water purification.

In the case of the FCWTF, the concentration of the flocculating agents (alum in this case), the zeta potential and the turbidity are monitored and adjusted during each work shift, each day. Figures 1 and 2 provide a view of the water treatment facility's control charts obtained over the one year period in 2002. Figure 1 has an expanded scale for turbidity and zeta potential to demonstrate how turbidity and zeta potential fluctuate in a typical train (settling tank) within the target range set for the treatment process.

### 3.1 Zeta Variation in Single Train

It is important to note the range of values on the axes of Figure 1. On the y-axes, zeta potential ranges from -6 to +6mV and turbidity from 0 to 1.2NTU. The x axis shows time varying from January through December of 2002. These data indicate that a very narrow range of process control is achieved in the settling tank throughout 2002. By careful monitoring of the zeta potential and turbidity values over time, adjustments to the flocculating agent dosage can be made in a rational and optimal manner.

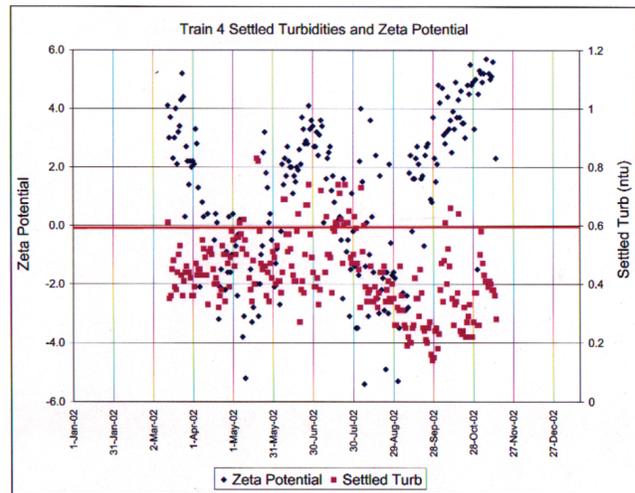


Figure 1: Water treatment control chart during 2002. Monitoring the zeta potential and turbidity results in a single train (settling tank).

### 3.2 Zeta Variation across Multiple Trains

Figure 2 shows data for zeta potential vs. alum concentration in the four settling tanks across the FCWTF. Further analysis of the data shown in Figure 2 indicates that seasonal changes do affect the process control. The goal of FCWTF is to maintain zeta potential results of their water production at approximately zero, specifically between the limiting values of +5 and -5mV.

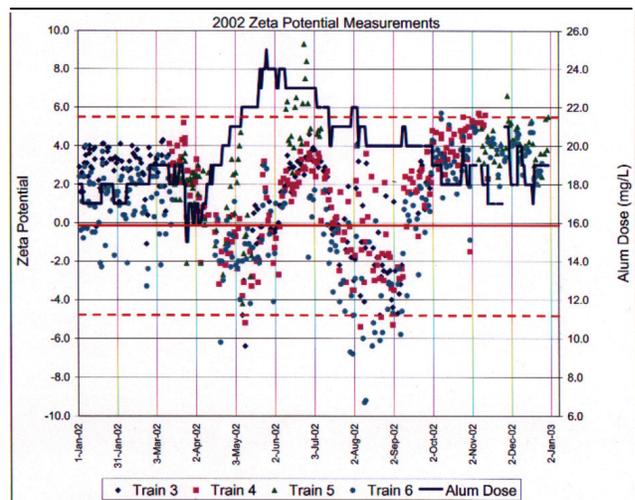


Figure 2: Water treatment production control chart in 2002 monitoring zeta potential results and Alum concentration across four trains or settling tanks in a US water treatment facility.

Because of requirements for thorough mixing of the flocculating agent with the incoming water supply, Figure 2 indicates a shift in the operational zeta potential range based on the changing water quality during what are

seasonal (April through May) changes that occur naturally to the raw incoming water supply at this location.

### 3.3 Zeta Variation due to Season

Figure 2 indicates that during the April to May time frame water production operated more on the negative side of the zeta potential control range and this produced the best floc and best water quality during that time period. The alum dose was also increased during this time because TOC levels were also increasing.

By the first week in June, TOC levels began decreasing but as shown in Figure 2 the alum dose was kept constant during the month of June (about 23 mg/L). A decreasing TOC concentration during June combined with a constant alum dose resulted in an increase in the zeta potential (increased TOC levels exert a very strong demand on alum and vice versa when TOC levels decrease less alum is required). The alum dose could have been decreased in June but due to an operational decision, in this specific case, it was not. Therefore, the zeta potential stayed on the plus side. By July, TOC concentrations in the water supply had dropped significantly and were no longer a factor so alum dose (concentration) was decreased.

During the late summer, FCWTF was operating on the negative side of the -5 to +5 mV zeta potential range, this produced the highest quality water at this time. However, by late fall and early winter, the operation was optimized on the positive side of the -5 to +5 mV range. In both events, this water production case study indicates that FCWTF remained within specification and in control of production efficiencies.

## 4 CONCLUSIONS

Zeta potential measurements can be successfully used in conjunction with turbidity measurements by plant operators as a key tool to help optimize the coagulation process and meet plant effluent goals. They are used as indicators of optimal dosage for flocculating agents: zeta potential as an indicator of particle stability and charge, and turbidity as an indicator of optical clarity and particle presence. Together they are good tools for determining the effectiveness of agents as well as optimizing the efficiency and economy of the operation of a water treatment facility. Frequent measurements of zeta potential have replaced the need to conduct jar tests to determine alum dose.

Zeta potential measurements are key parameters to monitoring and maintaining optimal conditions in water treatment facilities. This can be especially important during upsets or naturally occurring seasonal changes in water production. Zeta potential provides a measurable value that indicates potential production issues.

## REFERENCES

- [1] Letterman, R.D., A. Amirtharajah, and C.R. O'Melia, Ch 6: "Coagulation and Flocculation, In: Water Quality & Treatment," A Handbook of Community Water Supplies; 5th Ed. McGraw Hill, Inc. NY p6-58, 1999.
- [2] Zeta-Meter, Inc. 1993. "Everything you wanted to know about coagulation and flocculation." 4th Ed. Staunton, VA, p20, April 1993.
- [3] Dentel, S.K., "Coagulation Control in Water Treatment," Critical Reviews in Environmental Control, 21(1):41-135, 1991.
- [4] Sharp, E.L., J. Banks, J.A. Billica, K.R. Gertig, R. Henderson, S.A. Parsons, D. Wilson and B. Jefferson 2005. "The application of zeta potential measurements for coagulation control: Pilot plant experiences from UK and US waters with elevated organics." Water Science and Technology: Water Supply (in press).
- [5] Sharp, E.L., S.A. Parsons and B. Jefferson, "Coagulation of NOM: Linking character to treatment," IWA Particle Separation Conference, June 1-3, 2005, Seoul, Korea. Proceedings submitted for publication in Water Science and Technology. 2005.
- [6] Randtke, S.J., 1988, "Organic Contaminant Removal by Coagulation and Related Process Combinations," Journal AWWA, 89:5:64-77 (May 1997).
- [7] Owen, D.M., G.L. Amy, and Z. Chowdhury, "Characterization of Natural Organic Matter and its Relationship to Treatability," AWWA and AWWA Research Foundation. 1993.
- [8] Amirtharajah, A., C.R. O'Melia, Ch.6: "Coagulation Processes, Destabilization, Mixing and Flocculation," In: Water Quality & Treatment, A Handbook of Community Water Supplies; 4th Ed. McGraw Hill, Inc. NY, p269-365, 1990.
- [9] Stumm, W. and J.J. Morgan, Aquatic Chemistry, 2nd ed., Wiley Interscience, 1981.
- [10] Schroeder, E.E., Water and Waste Treatment, McGraw Hill, 1977.
- [11] Gregory, D., "Enhanced Coagulation for Treating Spring Runoff Water," Opflow, February 1998.
- [12] Billica, J.A. and K.R. Gertig, "Use of Zeta Potential to Optimize Full-Scale Treatment of High TOC Water," AWWA WQTC Conference Proceedings, 2006.