The Optimization of Coagulation in Drinking Water Processes (and Wastewater)

Initial Scan of Technologies, Background of Concepts

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Background and History:

One of the key processes in drinking and wastewater treatment is the removal of un-dissolved material prior to the filtration step. This is accomplished through chemical pre-treatment, where chemicals are added to the raw water to facilitate the coagulation, flocculation, and sedimentation of the material. The physical-chemical properties of the raw water impact the type and number of chemicals that must be added to achieve optimum coagulation and sedimentation. These include the pH, temperature, flow, and net particle charge of the raw water. A change in one or more of these parameters will typically affect coagulation.

The most common tests that have been run to determine the proper chemical dosages in the past are jar tests. These bench tests require the addition of different concentrations of coagulant to the pre-treated raw water to determine, visually, the best size floc particle that will form in a given amount of time. The tests are difficult to perform, require time, and operator expertise to generate a result. In light of the delivered result, the result is merely a snapshot of the process at that instant in time of sampling. Any change in the sample, flow or temperature characteristics mentioned above will potentially deliver a different result and require another jar test. Thus, the jar test has proven to be ineffective for the optimization of the coagulation/sedimentation process over time.

In an effort to be removed from continuous jar testing and acquire a means of better assessing the condition of raw water for proper dosing, technologies have evolved that have found success in the field of coagulation. Basically, there are three types of technologies that are available. One is streaming current or streaming potential technology, a second is zeta potential, and a third is imaging. Streaming current and zeta potential are discussed here. Of these technologies, streaming current or streaming potential has slowly evolved as a potential solution to assist the plant operator in proper dosing applications as the raw varies over time.

Colloidal particles and Coagulation

Waters that are suitable treatment generally will have some quantity of un-dissolved solids. The particles can be grossly separated upon particle size. Large particles that will settle rapidly and small particles will remain in suspension. Those particles that remain in suspension typically do so because of a combination of electrostatic forces between the surface charge characteristics of these particles and those of water molecules. These small particles are typically colloidal in nature and are 0.01 to 5 um in size. Examples include clays and silicates that are prevalent in many waters. Particles over 5 um in size will typically be large enough to have a settling velocity that will lead to its eventual separation from the fluid (water)[1].

These smaller particles have extremely slow settling velocities and cannot be practically removed by settling. Their behavior is highly influenced by electrostatic charge, in which the particles themselves are typically negative. These negative particles will repel each other, which prevents the particles from flocculation and eventual settling. Further, the electrostatic forces from these particles can be stronger than the force of gravity and will remain suspended. This Brownian motion theory applies to such particles. Thus, the purpose of coagulation is the neutralization of this negative charge between the particles so they can combine to a size that can be overcome by the forces of gravity and settle out of solution.

Monitoring Methods for Coagulation Efficiency:

Streaming Current:

Theoretically, the key to optimized coagulation is to have a net neutralized charge between the positive and negative particles after the coagulation has been added and the water has been thoroughly mixed. Since most waters have negatively charged particles, typically positively charged chemicals (coagulants) are added. The common cationic chemicals include alum, ferric chloride, and a number of long chain cationic polymers. Though less common, some waters that would have a net positive charge, such as those with low pH values, a number of anionic polymers are also available, though these situations are far rarer. The key for the operator of a water treatment plant is to know just how much of the chemical coagulant is necessary to achieve charge neutralization in their water, which would have a net charge is theoretically zero. This is where streaming current has found its use as a tool.

The technology and generally accepted theory on streaming current monitoring:

The following paragraphs provide the most common theory on streaming current. This theory has yet to be proven as universal across all conditions and samples. However, the technology if applied to a specific application can be used as a tool to help monitor and characterize a process that is relative to a set condition. It should be known that no set of application criteria will hold universal across all applications and the best use of the technology is for site-specific analysis and understanding on how the SCM values are impacted as a process is managed over time.

The steaming current sensor basically consists of a cylinder and a piston. The space between the piston and the cylinder is very closely spaced, with a distance of less than 25 µm. As the piston moves up and down, the counter ions in the water are forced a common direction of flow, which generates an electric current. This current, which is caused by the movement of the charged particles flows across electrodes to create an electrical circuit. The current in this circuit can be measured which is known as streaming current.

The piston's motion is sinusoidal, with a typical rate of 3-7 cycles per second. Thus, the resulting current generated is alternating and extremely low at approximately 10^{-12} amps. To produce a usable and constant signal, the current is amplified, rectified and filtered prior to being sent to a display or control device. The output is typically displayed nondimensionally and it is not calibrated to any actual particle charge[2].

There is no standardized methodology for measuring streaming current, and the magnitude of the current generated in any given instrument depends upon its respective design. This actual response is affected by a number of factors including the water chemistry, sampling conditions, and instrument design. Therefore, different responses will be seen with different waters and between different instruments. For this reason, most instruments provide either sensitivity or gain adjustment to vary the amplification of the signal to suit the specific application[4].

The application:

Streaming current instruments (SCI) measure the electrical charge characteristics of particles that are used to control coagulation and sludge conditioning processes. The instruments are typically installed online, downstream of coagulant or polymer addition. The post coagulation particle charge is used to monitor or control the chemical feed rate. A change in the streaming current value from a predetermined set point indicates that the coagulant dose is either lower or higher than optimum. SCIs provide information to help operators better control coagulant doses, resulting in chemical cost savings and consistent treated water quality. Further, streaming SCIs can help prevent fewer process upsets[4].

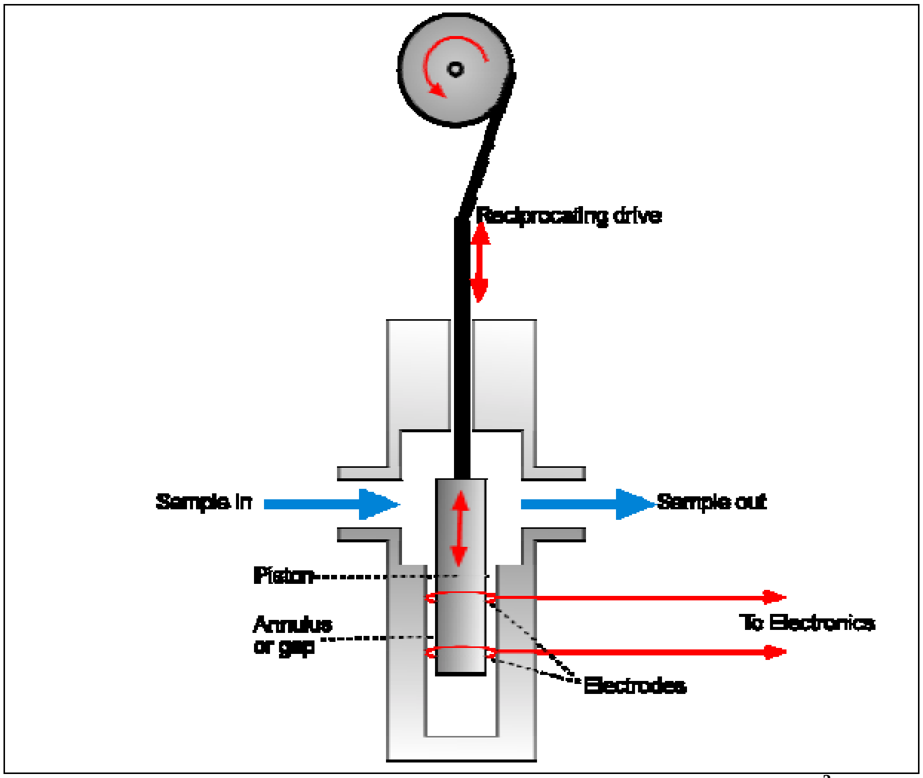

Figure 1 – Basic Description of a Streaming Current Instrument[3]

The use of this technology requires that the operator first learn what the optimized condition of coagulation is for their specific process. This is typically accomplished through a jar test or similar test that displays the optimum condition of coagulation. Under such a reference condition, the SCM will be set to a baseline, which typically assigns a value of zero to the display. Once this is accomplished, the streaming current is typically set to a value of 0, with 0 representing a water where the plant has a high confidence that coagulation conditions are optimized. Then, small deviations from this baseline can be used as indicators for feedback to dosing. For example, if the instrument has been set to zero and the value deviates in the positive direction, the dosage of coagulant can be reduced to reduce the positive charge in the water. The reverse would occur if the value deviated in the negative direction. Thus, it is common to provide this as a feedback loop into the dosing of the coagulant chemicals.

It is critical that the customer run these SCM experiments on their processes to determine the relative impact to any change that is made to the system. The SCM learning curve is steep, but over time the operator will understand how it best fits into the monitoring and optimization of a system. During this learning close attendance to the technology, the operations staff will learn what conditions correlate to changes in SCM. Examples can be partial or entire failures of different feed mechanisms, changes in chemical mixing, changes in raw waters, changes in contact times, SCM sensor maintenance and its respective impact on measurements. Some SCM changes will be easily correlated to upstream conditions or treatment evens, while others will require more study. But the key is to study how differences in treatment and operation impacts the overall stability of a charge neutralization process. The SCM technology is not such that it be installed, plugged in and then left to operate unattended. Instances where this has been the approach has resulted in disappointment in achieving the greatest value in the technology.

Customer feedback on the use and dosing application stresses the use of caution and patience on properly using this technology. There are many interferences that must be considered and mitigated in order to reduce error in its use. They stress the fact that this is not an instrument that can simply be plugged in and allowed to run. Rather, the application of the instrument itself must be optimized and closely monitored until robust operational and maintenance protocols have been developed for each site. Past success stories have yielded a list of items to be aware when using this technology[6]. These include:

- Sample Location – The location of the SCI is extremely critical because the unit should receive the sample immediately after the addition and mixing of coagulant chemicals.
- pH of Coagulation – The SCI has difficulty operating at high pH of coagulation for metal salts (e.g. iron).
- Conditions such as alkalinity will impact the responsiveness of SCM to changes in a sample stream.
- Raw Water Quality – Changing raw water characteristics and seasonal raw water temperatures can affect the SDI set point.
- Flow into the SCI – The flow must be consistent and representative of the sample. Flow must not plug the SCI.
- The "zero" set point of the SCI – The ideal "zero" set point varies seasonally and under different raw water characteristics. It is necessary to develop and maintain a standard calibration technique to maintain a common set point for calibration of the instrument.
- The application of lime to adjust pH – This technique can hinder the SCI in reading because it will coat the sensor. Therefore, proper mixing and ideal sample location can improve the operation of the instrument.

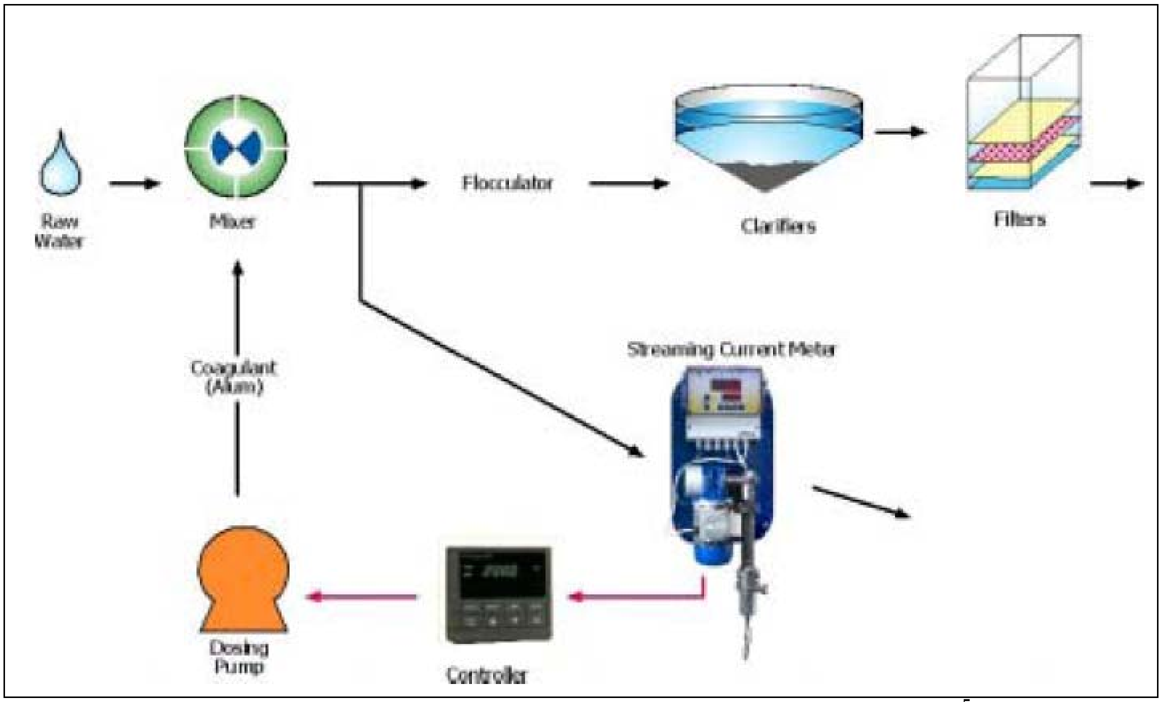

Figure 2 – Typical Application of a SCI for coagulant dosage control[5].

Zeta Potential

Streaming current is a derivative of Zeta Potential. Zeta potential is a charge analysis method to measure the relative mobility of charged particles in an electric field. The apparatus typically consists of two flat plates that are separated by approximately 0.1 mm and having an electrode at each end of the cell that is filled with the water containing the suspended material. When an electric potential is applied, the movement of particles toward one of the electrodes is observed. This movement is related to the applied potential, which is the Zeta Potential. It is again directly related to this measured speed of the particles.

Zeta potential is not necessary straightforward to calculate and is subject to many interferences including: the fluid's viscosity, dielectric constant, conductivity, and temperature. Further, it can only be determined for particles that are large enough to be detected and tracked through a microscope. It is thus a slow and labor-intensive measurement and cannot be used as an online monitoring tool. It is not very accurate near zero, which is the point of greatest interest, which is when coagulation, theoretically is optimized. Due to these reasons, Zeta Potential is not one of the candidates for use in coagulation optimization[7].

References:

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Appendix A – Contact Information to OEM's