The use of Streaming Current Monitors in optimising coagulant dosage in Water Treatment Plants.

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ABSTRACT: All water sources contain a mixture of organic/inorganic particulate or dissolved contaminants, in addition to microbes (i.e. bacteria, viruses and protozoa), which can be pathogenic (i.e. disease causing) to humans. Irish Water introduced 'The National Disinfection of Drinking Water' strategy in 2016 to ensure compliance with the European Communities (Drinking Water) Regulations, S.I. No. 122. One method of purification of raw water is the introduction of a chemical coagulant for the removal of particulate or dissolved contaminants through coagulation and flocculation.
Coagulant is dosed along with pH correction chemical to ensure the correct metal hydroxide floc formation for optimum organics removal. A coagulant is dosed at a rate/volume based on achieving and maintaining suitable chemical dosing conditions in responses to changing raw water conditions. The plant operator may face challenges during a rainfall event because the turbidity of the raw water can change, causing difficulties in maintaining the optimum coagulant dose.
A Streaming Current Monitor (SCM) can be used to automate the coagulant control process. A SCM is a continuous sampling, online instrument that enables the treatment plant operator to know precisely, and at all times, the optimum coagulant dosage. The SCM responds to changes in raw water characteristics (turbidity, pH, colour, etc.), flow rate, and allows the operator to make the necessary adjustments if required. This paper describes the introduction of a SCM to a Water Treatment Plant (WTP) in Galway County Council, Western Division and the calibration of this instrument to the WTP. The effectiveness of the SCM to optimise coagulant dosage automatically on a real-time basis in the WTP is also investigated.

KEY WORDS: Water Treatment; Coagulation;

1 INTRODUCTION

In Ireland, there is now a national water utility company called Irish Water (IW). The Irish Government through the Water Services Act established IW with a mission statement to provide “safe, clean and affordable water and waste water services”. IW introduced ‘The National Disinfection of Drinking Water’ strategy to ensure compliance with the European Communities (Drinking Water) Regulations, S.I. No. 122. This brought with it primary objectives of Water Treatment Plants (WTP) such as;

- to maximise the reduction of particles and microorganisms/pathogens.
- to maximise Total Organic Carbon (TOC) removal.
- to minimise the residual coagulant concentrations
- to minimise operating costs.

All water sources contain a mixture of organic/inorganic particulate or dissolved contaminants, in addition to microbes (i.e. bacteria, viruses and protozoa), which can be pathogenic (i.e. disease causing) to humans. TOC is a combination of the dissolved small organics (DOC) and the larger visible particulates. One such method of purification of raw water is the introduction of a chemical coagulant for the removal of TOC through coagulation and flocculation. The presence of TOC is measured by analysing the turbidity of the water. Turbidity is a measure of the degree to which water loses its transparency due to the presence of suspended particulates. In order to maintain a turbidity below 1.0 Nephelometric Turbidity Units (NTU) in water leaving the Water Treatment Plant (WTP), optimum coagulant dose must be maintained at all times. Potentially, the plant operator may face challenges during a rainfall event, as the turbidity can rapidly change causing difficulties in maintaining the optimum coagulant dose. A Streaming Current Monitor (SCM) can be used to automate the coagulant control process. This paper analyses if a SCM effectively increases and decreases the dose of coagulant automatically in response to changing water quality. It will also review the SCM ability to optimise the coagulant dose in a WTP over time.

2 WATER TREATMENT PROCESS

Raw ground and surface water that enter a WTP, contain a number of different compounds present that must be removed if the water is to be used for drinking water purposes. These compounds can be broken down into three categories; suspended solids, colloidal solids and dissolved solids. Suspended solids have a diameter larger than 10^{-6}m, colloidal solids between 10^{-9}m and 10^{-6}m and dissolved solids smaller than 10^{-9}m. Particles with a diameter larger than 10^{-5}m, and a specific density larger than 2,000kg/m^3, will settle in water. Smaller particles will also settle, but more slowly [1].

To remove the smaller particles from the water, the particles must be made larger. This is achieved by the introduction of a coagulant into the water so the particles flocculate together. Water treatment generally follows the same process through most WTPs; however, the scale and flow will vary greatly from plant to plant. As outlined in the flow diagram in Figure 1, the raw water flows into a raw water storage tank & the level is controlled via an actuated valve. Raw water is then pumped to the coagulation tank. Prior to entering the tank, the water is dosed with pH correction chemical, such as sodium hydroxide, followed by dosing of a coagulant such as aluminium sulphate.

The coagulated raw water flows in the first stage flocculation tank where it is mixed and flocs begin to form. A pH sensor is in the flocculation tank is used to maintain the coagulation pH by automatically adjusting the sodium hydroxide dose.

The water then exits the flocculation tank at low level and discharges to the Clarifier tank. Immediately on entering the Clarifier/Sedimentation tank, the flocculated particles begin to get heavier and fall to the bottom of the tank where the sludge is removed. The water then moves onto the sand filtration tanks, which filters the water to remove any remaining aluminium sulphate that may be present in the water. The treated water is discharged from the sand filter unit where it is dosed with hypochlorite for final disinfection. The water enters the treated water reservoir for storage. Water is pumped from the reservoir to the distribution network that services the various dwellings and industries on the network.

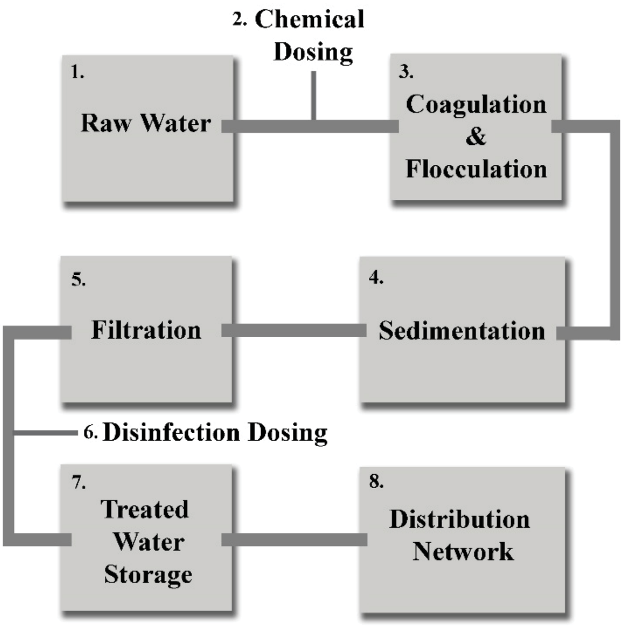

Figure 1. Water treatment process

3 COAGULANT DOSING

In a colloidal suspension, prior to the introduction of a coagulant, particles will settle very slowly or not at all because the colloidal particles carry surface electrical charges that mutually repel each other. Coagulants neutralise the negative electrical charge on particles, which destabilises the forces keeping colloids apart. Water treatment coagulants are comprised of positively charged molecules that, when added to the water and mixed, accomplish charge neutralisation [2].

Coagulant is also dosed with pH correction chemical such as sodium hydroxide to ensure the correct floc formation for optimum organics removal. A coagulant is dosed at a rate/volume based on achieving and maintaining suitable chemical dosing conditions in response to changing raw water conditions. The dosage is determined by carrying out of jar testing on a raw water sample. Jar Testing, in accordance with Irish Water guidelines, is used to select and quantify a treatment program for removal of suspended solids or oil from raw water. Jar tests are conducted on a six-place stirrer, which simulates the mixing and settling conditions experienced in the WTP. Jars with different doses of coagulant are run side-by-side, and the results compared to an untreated jar, or one treated with the current program.

The dose is an estimate and frequently raw water conditions might not at times be suitable, so the optimum dose can vary which causes difficulty for the plant operator.

3.1 *Importance of correct Coagulant dosing*

The results of insufficient coagulation include poor finished-water quality, high chemical costs, short filter runs, high backwash costs, excessive sludge, increased pumping costs (raw and finished) and post precipitation. Every water-plant operator's goal is to maintain good finished-water quality, which in large measure depends on the operator's maintaining proper coagulant dosage. Jar testing has inherent drawbacks, such as not offering real-time results.

Many WTPs still use manual control for coagulant dosing. If the raw water source quality is steady, this can still be considered an effective method of coagulant dosing. However, when the raw water changes then manual control of the coagulant dose becomes problematic. This can be challenging when WTP's are unmanned. When the raw water is likely to be of poorer quality in the future; (e.g. a weather forecast predicts a rain event) operators often increase the coagulant dose in anticipation of a rainfall event. This can lead to poor coagulation prior to, during, and after the rainfall event (if it comes at all) and can introduce longer-term issues such as filter blinding, shorter filter run times and increased aluminium residuals. Coagulant can enter the finished process water because of poor coagulation, alum overfeed, or poor pH control.

Figure 2 below shows the effect of adding a coagulant for the removal of impurities in water. Over dosing of coagulant is where there is too much coagulant chemical for the volume of impurities and can result in coagulant carry over to the sand filters and ultimately into the treated water.

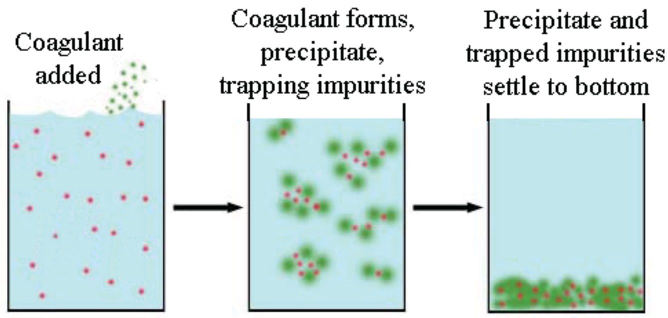

Figure 2. Removal of impurities by coagulation [3]

4 STREAMING CURRENT MONITORS

The most critical time in the water-treatment process usually occurs within the first two minutes of the raw water entering the plant. This is where an automated dosing system in the form of a Streaming Current Monitor (SCM) can prove to be very beneficial.

A SCM is a continuous sampling, online instrument that enables the treatment-plant operator to know precisely, and at all times, the optimum coagulant dosage. The SCM responds to changes in raw-water characteristics (turbidity, pH, color, etc.) and flow rates, and allows the operator to make the necessary adjustments if required. The SCM is a charge-measuring device. The charge measured is the net ionic and colloidal surface charge (positive and negative) in the sample being tested. The SCM samples continuously, which in turn eliminates the errors in the operators sampling. The SCM allows the user to accurately control the addition of the coagulant to maintain a set point charge reading that correlates to optimum treatment results. The ability to measure charge responses associated with both organic and particulate contaminants is what allows SCMs to reliably optimise coagulant dosage.

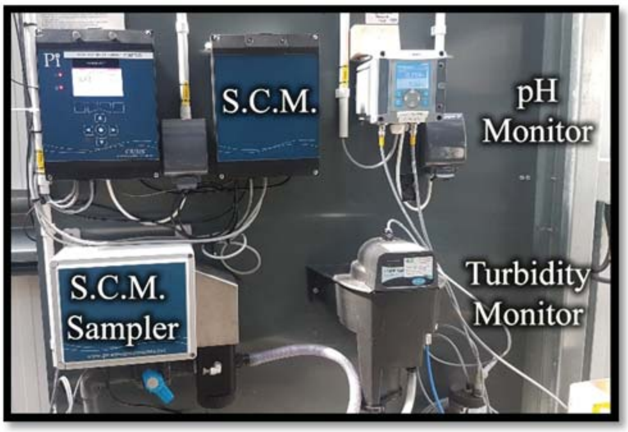

Figure 3. Wall mounted SCM

4.1 Positioning of the Streaming Current Monitor

Positioning of the SCM can be critical in the overall operation and success of the device. The Streaming Current Analyser should be installed as close to coagulant injection as possible. Ideally, the sensor will sample directly out of the static flash mix where the coagulant is added, or directly after a static mixer. Figure 4 shows a typical layout of a WTP with the location for the SCM. The process shown would be considered a conventional water treatment process. The sample for the SCM must be taken at a point where uniform distribution and mixing of coagulant is obtained for all flow rates. A poor sample location or poor mixing can render the SCM ineffective for control of coagulant dose.

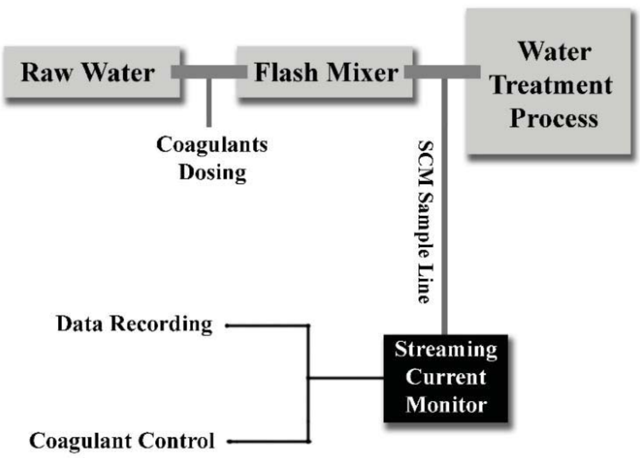

Figure 4. Positioning of SCM

4.2 How a Streaming Current Monitor Works

The general layout of the SCM sampler is shown in Figure 5. The sampler device itself is relatively simple and requires little maintenance, which is advantageous from an operator's perspective.

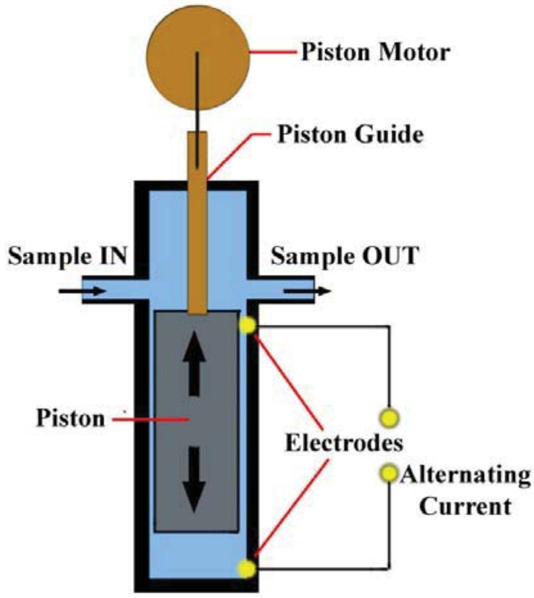

Figure 5. SCM sampler

The treated water sample flows into the sample cell as shown above where it is drawn into the bore during the upstroke of the piston cycle and is expelled from the bore on the piston down stroke. Particles contained in the water are temporarily immobilised on the piston and cylinder surfaces. As the water is moved back and forth by the piston, charges surrounding these particles (+ and -) are moved downstream to the electrodes. This movement of like charges causes an alternating current to be generated, defined as "streaming current." A coagulation analyser uses streaming current measurement to maintain proper electro kinetic charge (ionic & colloidal) in the treated water [4].

5 CASE STUDY: LEENANE WTP, CONNEMARA, CO. GALWAY

The village of Leenane, Co. Galway has a water treatment plant operated by Galway County Council, which serves a population base of approximately 600 with a large tourist influx in the summer months. The plant operates using the conventional treatment method consisting of chemical pre-treatment, flocculation/diffused air flotation, filtration and disinfection. The plant has a flashy mountain source, complete with raw water balancing tank, which means the turbidity of raw water can vary according to weather conditions and difficult to achieve optimum coagulant dose. A trial to achieve coagulant optimisation and improved TOC removal while maintaining finished water turbidity's below 0.30 NTU was undertaken in 2017. A Process Instrumentation (Pi) Streaming Current Monitor was installed to monitor the effectiveness and control of it coagulant dose on a real-time basis.

5.1 *Leenane WTP treatment process*

Leenane WTP process consists of the following stages; raw water tank, coagulation, flocculation, diffused air flotation (DAF) and rapid gravity filtration (RGF). To ensure compliance at all times, online monitoring of the raw water ultraviolet transmittance (UVT), turbidity and colour takes place. In addition, the treated water UVT, colour, pH and turbidity is also monitored. A fully automatic coagulant control system in the form of an SCM is in operation.

The treatment process commences with the addition of sodium hydroxide to the raw water. The addition of sodium hydroxide is intended to increase the raw water pH so that when aluminium sulphate is subsequently added, the resulting pH will be about 6.2. The addition of aluminium sulphate without any sodium hydroxide would result in a pH of less than 5. At such a low pH, little or no coagulation would result (no floc) and soluble aluminium in the treated water.

The flocs formed following addition of the chemicals are mixed with a saturated air recycle that disperses micro bubbles. The flocs will float to the top and form a mousse. A mechanical scraper is used to remove this as sludge from the surface. Clarified water then passes under a baffle and over a weir to the filters. Filtration removes floc particles left over which further reduces the turbidity and organics content of the water. The water is further disinfected when it is passes through an ultraviolet light reactor. Finally, the water is chlorinated. To be effective, chlorination needs adequate time and concentration. Finally, the treated water leaves the plant at a pH that allows the water to be chemically stable. It also has a residual of free (unreacted) chlorine in it that will remain in the treated water throughout its journey time to the extremities of the water distribution network.

5.2 *Calibration of Streaming Current Monitor*

When the SCM was put into service at the Leenane WTP, it took approximately 2 hours for the reading to stabilise. This was because the probe and piston needed time to fully condition their surfaces with the soluble and colloidal species in the water, and to reach an equilibrium with the sample. Once the sensor has reached stabilisation, the response to normal changes in water quality and coagulant dosing is much faster than the initial conditioning time.

The dosing was set as per the Jar Testing results for optimum coagulation and the SCM was set to fully automatic control. Typically, a period of 1 hour passed after setting the optimum dosage for the Streaming Current value to stabilise. Once stable, the reading seen on the display was used as the set point value by which future dosage adjustments were made. This set point was adjusted slightly over several months and aluminum residuals tests in the treated water were carried out to ensure that optimum coagulant dose was being maintained and no carry over of aluminum was occurring.

Figure 6 below is a graph indicating the consequences of setting the dose set point above or below the correct value determined by jar testing. If the operator sets the dose far away from set-point then the SCM control will take longer to reach set-point as it may over-dose/under-dose until it recovers.

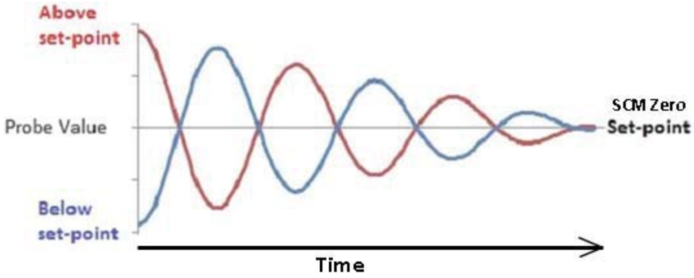

Figure 6. SCM set-point stabilisation graph

6 ANALYSIS OF RESULTS OF SCM TRIAL AT LEENANE WTP

During the calibration phase of the SCM it was found that the dose rate, as found in the Jar Testing, was above what was required to achieve charge neutralisation of the water through the SCM. The dose was slowly decreased and water quality was monitored to ensure optimum water quality results were being maintained. The SCM operates on a pump percentage dose of pump to within 0.1% which allows for a more accurate dose rate as opposed to the conventional method of dose control through the Human Machine Interface (HMI). The dose adjustment through the HMI is also based on the results of ongoing jar testing and must be adjusted manually, which will not take into account varying raw water quality on a real-time basis, this is a major advantage of the SCM having a real time dedicated sampler that adjusts the dose accordingly.

To illustrate the effectiveness of the SCM, the aluminium sulphate residual in mg/l for a 5-day period in automatic dose through SCM and a 5-day period of manual dose also through SCM is shown in Figure 7. The raw water quality for the each of the 5 day periods both in manual control and automatic control averaged at approximately 84% UVT. The residual was taken at the same time each day by the Caretaker on site.

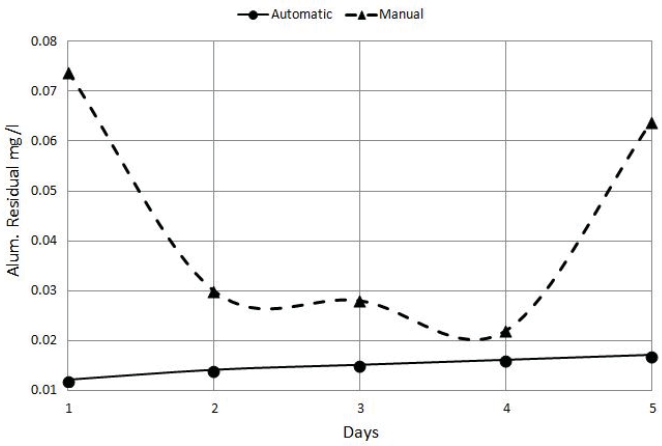

Figure 7. Treated water aluminium sulphate residual

The graph illustrates the fluctuation in alum residual due to the varying dose and raw water quality while in manual dose control. The residual for automatic dosing is maintained relatively consistent over the 5-day period which indicates more accurate dose and thus saving on the aluminum sulphate being used at the plant. When the dose rate of both the manual and automatic controls are developed, it can be seen that for the 5-day study period the manual dose was 37% higher (by volume) than the automatic dose through the SCM.

As the water quality changes, so must the dose rate to maintain optimum dose. The dose rate for the same 5-day period is shown in Figure 8. In manual control, the caretaker adjusts the dose during the day to maintain optimum dose. However, this is just a snap shot in time and is not reflective of the required dose. Based on the comparison with the automatic dosing, it appears that the manual control resulted in over-dosing. The automatic dose however increases and decreases gradually which reduces the spikes in dosing which saves on chemical and is best practice for plant operation to avoid spikes in chemical dosing which can have adverse effects on sand filters.

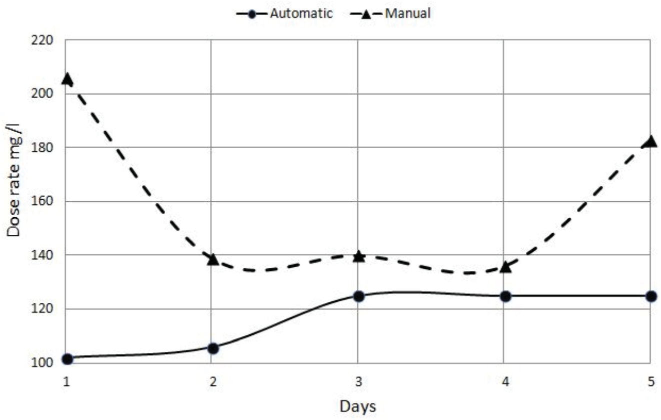

Figure 8. Aluminium sulphate dose rate

7 OUTCOMES OF SCM AT LEENANE WTP

Several initial problems were identified at the calibration stage of the SCM such as inadequate mixing and defective pH probes. However following correction of these issues, it was found that if the correct coagulant dosage is set on the SCM then it will track changes in the raw water to maintain a zero reading on the display indicating the negatively charged particles have been neutralised in the raw water and thus optimum dosage.

7.1 Advantages of a Streaming Current Monitor

There are a number of advantages for the plant operator by having a fully calibrated, functioning SCM:

- Maintain high quality finished water through automated coagulant dose.
- Reduce coagulant chemical cost due to reducing overdosing.
- Ensure coagulation reliability and reduces risk of incorrect dosing.
- Improve filter performance due to reducing overloading from incorrect coagulant dose.
- The SCM has high and low alarms that can be set to alert the operator to treatment upset.
- Performs accurately and reliably at all turbidity levels normally encountered in WTP.

It should also be noted that the SCM requires ongoing calibration and maintenance and may respond poorly if the changes in water quality are severe.

8 CONCLUSIONS

The streaming current monitor can be a useful tool in coagulant optimisation. It is not a typical plug and play on-line instrument, as it requires operator input and adjustment to develop the optimum dose. The SCM requires an understanding of the treatment process including the mixing dynamics and chemistry of coagulation. It is also important that ongoing tests are conducted on the treated water to ensure the SCM is reacting to the changeable raw water conditions.

During the calibration stage at Leenane WTP, the SCM failed to adjust accordingly to large changes in raw water quality. However, following the introduction of maximum and minimum dosage limits this problem was overcome. During the calibration process, many important details were noted with respect to using the SCM:

- Proper location of the instrument – the sample point for the instrument must be located in a position that will not be affected by sediment in the pipe and will also obtain a representative mixed sample.
- Routine maintenance and cleaning of sensor – the sensor and piston must be cleaned and maintained to ensure data is being based on a clean sample.
- Proper sample delivery to sample cell – when the plant turns off the sample cell can become starved of a sample which will result is a poor sample on re-starting of the WTP, a motorised valve was installed on the feed pipe to close and maintain water in the cell on plant shut down.
- Standard calibration procedure – When an issue is encountered it is essential to have a calibration procedure to troubleshoot any problems that may have developed.
- Protocol to establish baseline value for optimised coagulant dosage – A standard dose rate for various raw water UVT is recorded over time by the Caretaker to ensure he/she has a baseline for dosing when switching to manual control or when switching from manual to automatic control.
- On-line data display to see the data trends – trends can be accessed and analysed on a real-time basis which allows the operators to develop an understanding of the SCM reaction to varying water qualities.

If the above points had been implemented earlier, it would have led to a more streamlined calibration process.

While the SCM is considered an automated instrument, it still requires user input. This is generally a misconception of the SCM as initially the operative felt the SCM would mean less time attending the WTP. Galway County Council routinely perform jar tests to compare the optimal coagulant dosage as a method to confirm the baseline SCM reading. The ability to periodically confirm the baseline SCM reading helps to validate the reliability of the instrument.

Galway County Council have successfully used the SCM for coagulant optimisation, storm events and feed equipment failures. The streaming current monitor responds well to changing raw water conditions and enables the process control caretaker to trim coagulant dosages. In the 5-day study period a 37% difference (by volume) was experienced in the dosing rate. This could lead to potentially significant savings in large

WTP's. However, the low dose rate at Leenane WTP means that chemical cost reduction due to the SCM’s efficient dosing is negligible. Nevertheless, its main benefit is the adjustment of a dose in a rainfall event.

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