THE USE OF CHITOSAN IN WATER TREATMENT -AN ASSESSMENT OF PRACTICAL APPLICATION.

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Abstract

The practical aspects of the use of chitosan in water treatment have been evaluated in a five years research project involving several water treatment plants and research organizations. The evaluation has included long term operation in real water treatment plants as well as hundreds of tests in pilot plants and in laboratory. The study has proven that the use of the chitosan product KitoFlokk™ from Norwegian chitosan ltd. is well suited for use in water treatment. It has been approved for addition to drinking water and is now in use in several waterworks on a permanent basis. Using Kitoflokk™ imply a series of valuable benefits, such as no concern about treatment chemical residuals, a significant reduction in waste, a more stable water quality and improved operator handling safety. The waste origin from the water treatment has also proven to be able to improve harvest when used as a soil improver.

Background.

Water treatment using coagulation is a well established process worldwide. It is suited for removal of natural organic matter, particulate matter, metals and microbiological matter.

As for all methods, there are also draw backs from using this technology. The coagulant has traditionally been a synthetic chemical based on a metal salt such as aluminium or iron. This has three distinctly undesired consequences:

- Metal residuals in the drinking water
- Large production of waste (sludge)
- The sludge is an environmental pollutant

Chitosan may be used as an alternative to the traditional metal-based coagulants. Chitosan is a natural organic product, free of metals and will therefore eliminate the problem of metal residuals. The sludge volume using chitosan is considerably lower than when using metal-based coagulants. Due to the natural organic character of chitosan, it is also expected that the negative impact of the sludge as a waste is reduced.

However, there have been several unknown aspects of this method. These aspects range from practical challenges on how to handle the new product to the more intricate question of legislation, in addition to the many unknown consequences for water quality, filtration behavior, biofilm formation and disinfection by-products.

The work presented is a summary from the investigation and assessment of practical conditions and theory associated with the use of chitosan as a coagulant/flocculant in water treatment. A comprehensive theory of coagulation and filtration has been offered, as well as an introduction to particles in water and their measurement.

Most investigations are performed on typical Norwegian surface water, rich on NOM and low on particle concentrations. The investigations are tailored for contact filtration, but most results are proposed valid for all coagulation / filtration processes.

The work has been done with great availability of equipment and resources, allowing for the introduction and evaluation of rather advanced instruments such as particle counters, particle monitors and online streaming current detectors.

The following is a summary of results and findings from this work

Chitosan products

The study has included more than 40 chitosan products from a total of 7 producers in Europe, USA and Asia. Some products have been excluded already during lab-trials, while others have been subjected to full-scale testing for several years.
The trials have revealed that the characterization of chitosan from most producers could be more accurate. In more than one occasion, products with identical certificate of analysis have had significantly different treatment efficiency. It is also found that there exists important features that may not be detected using ordinary quality parameters.

Another important finding is that the regularity of supply in the chitosan market is very variable. In a water work, consistent quality has to be delivered time after time for a supply 24 hours a day – 365 days a year. This is a factor that separates suppliers more than their ability to provide single sample quality of a good price.

Chitosan coagulation

For raw water qualities typically found in Norway (High NOM, low particulate), the dominating coagulation mechanism is charge neutralization. However, if the particle concentration in the water is considerable (above 20 NTU), the bridging mechanism is believed to be more influential.

The optimum chitosan quality is dependent upon the local raw water characteristics.

Due to the charge neutralization mechanism, streaming current measurements has proved to be a suitable tool for coagulant feed control. As charge density is not the only significant quality parameter, also other feed control parameters has to be included.

Filtration

The removal efficiency for particulate material is excellent when using Kitoflokk™. The treatment efficiency is usually 99% or higher. The high particle removal efficiency is achieved even during sub-optimal conditions, such as lower dose than optimal or poor pH control.

The filtration cycle is a more dynamic process than revealed by turbidity readings. Using particle counting, it has been shown that varying particle sizes exhibits different filtration behavior and experiences ripening and breakthrough in an individual way. Particles in the range 2-4 μm experiences a very long ripening period, improving removal efficiency almost continuously during a filtration run. Particles in the range > 10 μm ripen quickly and will experience breakthrough much earlier than for smaller particles. The turbidity measurements may not offer any signs of this.

Increased velocity of filtration causes particles to be driven deeper into the filter, improving the utilization of the filter and causing slower head loss development. However, higher velocity of filtration yields poorer filtrate.

One key benefit from using chitosan is the low sludge production that causes the filtration run time to be extended by 80-120% compared to when using polyaluminiumchloride (PAC). The effect of lower sludge production has several positive gains, such as:

- Higher net water production
- Less filter head loss development
- Less loss of water for back flushing of filter
- Less chemical consumption
- More stable water quality
- Less costs in back flush water treatment system
- Less sludge
- Less energy consumption
- Less environmental damage

It has been shown that the consequence of an induced break through, such as from a pulse of increased filtration velocity, is dependent upon the filter run progress. If the break through is initiated early, and the filter are still un-utilized, the filter will recover and continue to produce high quality water for the rest of the filtration run. If the break through are initiated close to saturation, it may trigger a breakthrough that the filter never recovers from. The detachment of previously attached particles is a significant mechanism, as particle loading leaving the filter is higher than particle loading onto the filter during a break through.

The early break through of larger particles during a filtration run is not necessarily the same larger particles entering the filter, but rather fragments of aggregates of particles in all size ranges. This effect causes the use of particle counting for monitoring hygienic barrier to be a conservative measure for larger organisms such as Cryptosporidium.

NOM removal and practical consequences
Using Kitoflokk™ as coagulant may successfully be used for removal of NOM. The removal efficiency depends on raw water characteristics and process conditions, but is typically 50-80% measured by color improvement and 20-40% measured as TOC. This is lower than what is commonly achieved using traditional coagulants such as PAC.

It is generally considered that it is the smallest size fractions of NOM that are most prone to biodegrade, causing growth of microbiological species in the distribution net. As chitosan is effective also for the smallest fractions, the potential for biofilm formation is reduced. Other water quality analysis such as AOC and BDOC show different results from plant to plant.

Direct measurements and investigations of biofilm in the distribution system before and after applying treatment with Kitoflokk™ reveal significant reduction in both concentration and mass of biofilm.

Experiments performed by chlorinating different size fractions of NOM reveal that it is the smallest molecules that contribute the most to the formation of chlorination by-products.

Hygienic barrier
The use of Kitoflokk™ as coagulant in coagulation/filtration plants should be considered a hygienic barrier. As it is not so sensitive for process conditions such as pH, dose and changes in raw water quality, it is considered to be a more robust barrier than PAC.

The hygienic barrier may be compromised by process upsets commonly experienced on water treatment plants, such as sub-optimal dose or increase in filtration velocity. This finding is believed

to be valid for all coagulation/filtration plants. The reduction in hygienic barrier is limited for the process upsets investigated. In fact, the barrier against parasites measured as Cryptosporidium Parvum is never compromised.

Particle counting and particle monitor have been found to correlate with certain microbiological agents. These instruments may successfully be used as indicators of hygienic barrier.

Sludge
Using chitosan as a coagulant will reduce one of the major major drawbacks of water treatment using coagulation, the sludge. When Kitoflokk™ is utilized, the sludge volume is generally reduced by approximately 50%. The metal content usually associated with water treatment sludge is practically absent, altering the characteristics of the sludge from an environmental problem to a possible resource. The water treatment sludge from using Kitoflokk™ has been shown to be able to significantly increase the harvest of some plants. This effect is depended on plant species and does not apply for all plants. The back flush water does not exhibit a toxic effect on salmon, and pass standard toxicity tests. It is expected to inhibit a low oxygen demand in a recipient.

Overall assessment
The fact that chitosan is a natural organic substance seems to appeal to water work owners reluctant to use metal in their water, particularly for plants frequently experiencing problems with metal residuals.

Using chitosan as a coagulant should also be of interest for water treatment plants with high sludge treatment and disposal cost or environmental challenges:

- Costly sludge disposal (the need for costly thickening and dewatering – transport and disposal)
- The sludge causing environmental damage (aluminium leaking onto the environment)
- Difficult back flush water disposal. This is especial valid for smaller water works were establishment of sludge treatment is often too costly and a simpler back flush handling is desired.

Based on the investigations presented, release of back flush water into a suited recipient should be possible without any more treatment than maybe a hydraulic distribution of the flow. The sludge is not toxic.

For the water treatment plant choosing to treat the back flush water into sludge by thickening and dewatering, using chitosan will reduce the needed investment due to the lower sludge throughput. The finished sludge should not need to be disposed in a landfill, but may successfully be used as a soil improver. One may even consider making the sludge into a value added product to be sold to nearby greenhouses etc.

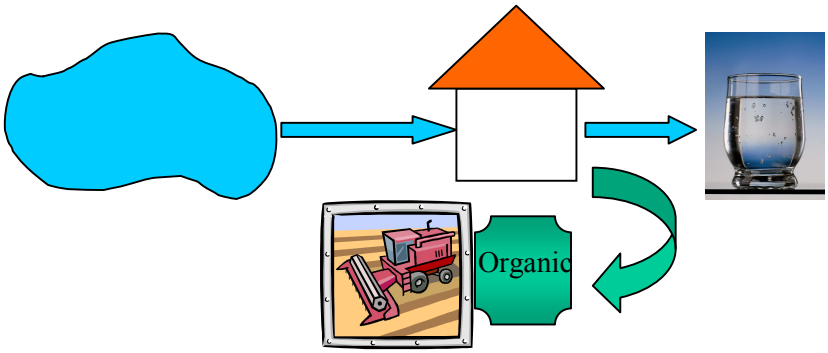

Figure 1 : Water treatment cyclus using chitosan as coagulant

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