Institution: Cranfield University		
Unit of Assessment:12		
Title of case study: Process optimisation at water treatment works using zeta potential		
Period when the underpinning research was undertaken: 2004-2018		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Peter Jarvis	Professor of Water Science and Technology	2005-present
Bruce Jefferson	Professor of Water Engineering	2000-present
Period when the claimed impact occurred: August 2013 - December 2020		
Is this case study continued from a case study submitted in 2014? Y		

1. Summary of the impact (indicative maximum 100 words)

Cranfield University research has transformed the way water utility companies operate drinking water treatment processes, delivering a wholesale change in the operation of coagulation and clarification processes. This has resulted in: improved drinking water quality and avoidance of quality failures; reduction in chemical application by up to 30% (a GBP3.6 million annual saving in the UK) and waste disposal costs; and the development of an online process control instrument.

Since 2014, 30% of the total water volume supplied in England, Wales, and Scotland (>4,500 million litres per day, MLD) has been processed by application of zeta potential across five of the biggest UK water companies. In North America, two of the largest water treatment works have also integrated zeta potential monitoring, processing 1,855 MLD.

2. Underpinning research (indicative maximum 500 words)

Research Background

Research has been focused on translating theoretical understanding of particle surface stability (Derjaguin–Landau–Verwey–Overbeek theory) to the optimisation and control of drinking water treatment systems that utilise coagulation, processes treating approximately 70% of all drinking water globally. Contaminants present in water carry a net negative charge (mineral turbidity, natural organic matter, bacteria and viruses, sewage particulates, and algae). This charge can be determined by measurement of the zeta potential (ZP) of particles and colloids present in the water. Cranfield's research has established strong relationships between the application of positively charged chemical coagulants and the optimised removal of these compounds as the net negative zeta potential is reduced below a critical threshold value.

This, for the first time, has developed operational windows of residual charge measured by ZP whereby contaminant concentration is minimised - meaning water treatment decisions can be made based on the mechanism of removal rather than the conventional practice of measurement of indirect surrogates (e.g., UV254, turbidity) and empirical testing.

Coagulation research
Work originated in a Water Research Foundation project led by Cranfield between 2004-2007 supported by five UK water companies struggling to effectively treat organic laden water sources (Severn Trent, Scottish Water, Thames Water, Yorkshire Water and United Utilities). The project resulted in ground-breaking publications on treating water sources containing elevated organic matter, establishing for the first time relationships between water characteristics (generated from natural organic matter (NOM), algal content, and sewage) and changes in net surface charge post coagulant addition. This has enabled universal optimisation of coagulation for water types dominated by different types of organic and inorganic materials [**R1, R2**].

Neutralisation of surface charge was shown - through work funded by Yorkshire Water at Cranfield in 2007-to 08 - to produce strong floc particle characteristics, resulting in enhanced removal of particles during clarification and filtration processes. This concept was instrumental in explaining the results obtained from research in 2012 into a new coagulant chemical (zirconium oxychloride) for enhanced removal of natural organic matter showing how more charge per mass of coagulant led to improved removal [**R4**].

Subsequent research between 2016-18, sponsored by Severn Trent and Scottish Water [**R3**] has been the first to show how application of online ZP in feedback control systems enables robust water treatment over a range of water quality conditions and hence enables transfer of long-standing theory into practical use.

Bubble modification
Understanding how to manipulate the surface charge on bubbles has enabled the development of low-chemical treatment processes for algae removal. Modification of bubbles - through the addition of cationic chemicals such as surfactants or polymers - enables algal capture to take place directly in dissolved air flotation clarification processes, negating the need for upstream coagulation [**R5**]. This work originated in a utility-sponsored PhD project at Cranfield on algae removal (2004 to07) to address an industry-wide problem of algae in source waters used for drinking water (Thames Water, Yorkshire Water, Anglian Water and Northumbrian Water).

Ion exchange and charge density
ZP has been used to measure the charge density of natural organic matter in surface waters, showing that novel water treatment processes like suspended ion-exchange (SIX) removes a particular fraction of NOM that enhances coagulation efficiency, providing increased removal of overall dissolved organic carbon (DOC). The component of NOM removed by SIX that had a positive impact on coagulation was identified to be charged, low molecular weight organic compounds of all hydrophobicity levels, challenging established beliefs [*R6*]. The charge density of the organic matter was shown to be the most important water quality characteristic that could be used to control the ion exchange process for removal of NOM. This work was undertaken in collaboration with Scottish Water and a university industrial studentship award, as well as a project funded by South West Water between 2014-16. The driver for the research was to improve the removal of organic matter and reduce disinfection by-product formation in water sources used for drinking in these water supply regions.

3. References to the research (indicative maximum of six references)

[R1] Sharp, E.L., Parsons, S.A. & Jefferson, B. (2006) Seasonal variations in natural organic matter and its impact on coagulation in water treatment. *Science of the Total Environment*, 363(1-3), 183-194. https://doi.org/10.1016/j.scitotenv.2005.05.032

[R2] Ncube, P., Pidou, M., Stephenson, T., Jefferson, B. & Jarvis, P. (2018) Consequences of pH change on wastewater depth filtration using a multimedia filter. *Water Research,* 128, 111-119. https://doi.org/10.1016/j.watres.2017.10.040

[R3] Smith, R., Montalban, L., Hassard, F., Worley, T., Sharp, E., Liu, P., Jarvis, P & Jefferson, B. (2019) Coagulation control using on-line zeta-potential measurements: Can it save money and improve performance? *Institute of Water Journal*, Issue 3, 6-7. https://issuu.com/instituteofwater/docs/1218_iow_journal

[R4] Jarvis, P., Sharp, E., Pidou, M., Molinder, R., Parsons, S.A. & Jefferson, B. (2012) Comparison of coagulation performance and floc properties using a novel zirconium coagulant against traditional ferric and alum coagulants. *Water Research*, 46 (13), 4179-4187. https://doi.org/10.1016/j.watres.2012.04.043

[R5] Henderson, R.K., Parsons, S.A. & Jefferson, B. (2009) The potential for using bubble modification chemicals in dissolved air flotation for algae removal. *Separation Science and Technology*, 44 (9), 1923-1940. https://doi.org/10.1080/01496390902955628

[R6] Finkbeiner, P., Moore, G., Tseka., T., Nkambule, T.T.I., Kock, L.D., Jefferson, B. & Jarvis, P. (2019) Interactions between Organic Model Compounds and Ion Exchange Resins. *Environmental Science and Technology*, 53(16), 9734-9743. https://doi.org/10.1021/acs.est.9b02139

4. Details of the impact (indicative maximum 750 words)

Water quality deterioration and stricter regulation have demanded that water treatment works (WTWs) globally have greater resilience. Coagulation and clarification treatment, processes that are used in more than 70% of all WTWs, have been optimised and controlled using methods such as batch jar testing or analysis of spectrophotometric properties of water constituents. These methods do not directly link to the mechanisms of removal of contaminants during the coagulation process. The following impacts have been realised through the application of zeta potential in water treatment:

1) Improved operational practice and drinking water quality

Cranfield's research has led to the new and widespread implementation of zeta potential monitoring (ZPM) into the routine operational practice of drinking water treatment optimisation and process diagnostics since 2015. ZPM has enabled the industry to rapidly identify relationships between contaminant removal and residual charge, and the root causes of treatment issues:

> '*The valuable work that Cranfield has been doing on zeta potential has had a significant impact on the way that we now manage and understand our coagulation processes'* [**S1**].

Since 2018, Scottish Water has used ZPM as a replacement for jar testing at all of its coagulation WTWs, some 120 sites that treat >80% of the drinking water volume in Scotland. Across the UK, ZPM has influenced treatment of >6,700 million litres of water per day (MLD) across five water utilities, approximately 30% of the total water volume supplied in England, Wales, and Scotland. [**S1**], [**S2**], [**S3**], [**S4**], [**S5]**.

Other specific water quality improvements include:

- South West Water - filtered water turbidity improved by a factor of 2.5 at a 10 MLD WTWs. This led to reduced risks associated with the microbial quality of the water; proactive management to extend filtration run-times and improve water quality; and rapid start-up of WTWs after shutdown [**S3**].
- United Utilities - ZPM used across all coagulation WTWs to: optimise coagulation, particularly during periods of source water quality deterioration; provide a regular check of the coagulant dose being applied; improve disinfection performance; optimise backwash water treatment; and determine the impact of powdered activated carbon on coagulant demand [**S5**].
- USA - two large WTWs in the Philadelphia metropolitan area (treating up to 1,855 MLD combined) have used ZPM to maintain optimal coagulant doses in-line with dynamic water quality changes over the last five years [**S6**]. For Fort Collins Water utility in the US, ZPM is a critical tool in its regular sampling protocols to optimise coagulant dose and improve water quality for 130,000 customers [**S7**].

2) Increased resilience and robustness of the coagulation process leading to the avoidance of water quality failures

Applying ZPM to live WTW sites has enabled systems to run at full treatment capacity during extreme weather events. Since 2016, it has enabled the coagulant dosing to be manipulated such that the system is always within the appropriate charge neutralisation zone. This has helped ensure that South West Water did not run out of water or need to impose a hosepipe ban across its region [**S3**].

3) Process optimization, enabling reduction in chemical application and waste disposal costs

- Since 2016: at Severn Trent on-line ZPM resulted in a coagulant reduction of $2 mg.L^{-1}$ (as Fe), representing a 20 to 30% annual saving in coagulant costs and a 10% reduction in sludge production and associated treatment and disposal costs [**S2**].
- Since 2017: for South West Water, GBP50,000 to GBP60,000 savings were obtained over 18 months for a 50 MLD WTWs that implemented coagulation control using on-line ZPM (30% reduction in coagulant dose) [**S3**].
- Since 2018: across coagulation drinking WTWs in the Scottish Water region, 20% annual savings were made in coagulant costs, and a commensurate 10% reduction in sludge disposal costs [**S1**].

Applying a 30% reduction in operational costs across all of the water companies constitutes estimated annual savings of approximately GBP3,600,000.

4) Development of an online instrument for process control

Since the completion of Cranfield's Water Research Foundation Project, a Cranfield researcher, Emma Sharp, now working for Severn Trent, collaborated with Malvern Panalytical to develop an on-line ZP monitor in 2014 based on Cranfield's underpinning science [**S2**]. This has been applied at a number of WTWs, including a 40 MLD site. Many more water companies have now installed on-line ZP instruments for enhanced monitoring and development of automated feedback process control systems for coagulation [**S1**], [**S2**], [**S3**], [**S6**]:

"*It's been interesting to see just how quickly the Water Industry is …adapting to the use of zeta potential as a valuable tool. It's unusual for research to be embraced by industry at such a pace, but it reflects the quality of the research and the respect that the water industry has for Cranfield's research agenda."* [**S1**]

5. Sources to corroborate the impact (indicative maximum of 10 references)

[S1]: Written testimonial outlining the significant and fundamental impact Cranfield's work has had on the optimisation of coagulation processes on the way Scottish Water now manage and understand their coagulation processes - Senior Project Manager, Scottish Water

[S2]: Written testimonial from former Cranfield colleague who has collaborated with Malvern Panalytical to develop the online zeta potential monitor - Area Operations Business Lead, Severn Trent

[S3]: Written testimonial outlining how South West Water is utilizing Zeta measurements to optimise coagulation processes at multiple sites to improve water quality and reduce the quantity of coagulant and pH correctant required - Head of Water Quality, South West Water

[S4]: Written testimonial explaining how robust evidence provided by Cranfield led to installation of the first 3 MIEX plants in Yorkshire, UK and Europe and use of bench top zeta potential for process diagnostics at coagulation sites - Innovation Technical Specialist, Yorkshire Water

[S5]: Written testimonial to explain how zeta potential is used across WTWs to optimise coagulation for the removal for dissolved organic carbon in water and is key to compliance - Senior Process Scientist, United Utilities

[S6]: Written testimonial explains how zeta potential research from Cranfield changed operational coagulation practice at Philadelphia Water - Principal Engineer, Philadelphia Water Department, Philadelphia, USA

[S7]: Written testimonial explains zeta potential monitoring as an integral part of water treatment at Fort Collins – Director of Plant Operations, Fort Collins Water Treatment Facility, USA