MAXIMISING PLANT CAPACITY – NOVEL INSTRUMENT TO MEASURE FLOC STRENGTH IN DIRECT FILTRATION WATER TREATMENT PLANTS

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ABSTRACT

Sydney Water faces unprecedented challenges due to increasing concentrations of natural organic matter (NOM) in raw water supplies, particularly at the Nepean Water Filtration Plant (WFP) (Western Sydney, Australia). A consequence of increasing NOM is reduced floc strength, which can lead to premature turbidity breakthrough in the filters, leading to higher backwash frequency and lower plant capacity.

A research project between Sydney Water and UNSW resulted in the development of a device that accurately mimics shear imparted on flocs. The research findings were converted by Instruments Works into a portable fit-for-purpose instrument for plant use. This crucial innovation was completed within six month period of the conclusion of the research project and delivered prototype device used by plant operators to assess the impact of water quality on flocs under real shear conditions in filters.

INTRODUCTION

Changes in the complexity of natural organic matter (NOM) in Sydney’s catchments has impacted the performance of direct filtration plants, resulting in reduced treatment capacity, increased chemical consumption and waste sludge production. Reduced water production is attributed to weaker floc strength which results in turbidity breakthrough, triggering an increase in backwash frequency (Mohiuddin et al. 2014).

Failure to successfully control the NOM issue could result in hundreds of millions of dollars of upgrades to the treatment processes at Sydney’s ten water filtration plants in the next decade. Consequently, NOM control is currently a top priority in Sydney Water’s Drinking Water Improvement Plan.

Higher NOM in the raw water demands higher dosages in treatment chemicals that results in increased solids to be filtered and also reduction in floc strength. The Nepean WFP produces around 40% less water after heavy rain events due to increase in NOMs. The length of time with reduced water produced is unpredictable and can last many weeks (Mohiuddin et al, 2014).

Efforts to optimise the coagulant (FeCl3) and cationic polyDADMAC dose to increase floc stability are hampered for lack of a suitable test for floc strength. Traditional methods that use impellers (Jar test) to generate turbulence induced shear are not suitable for direct filtration systems as it is difficult to identify a threshold velocity gradient which induces floc breakup and subsequent breakthrough of suspended solids (Jarvis et al., 2005). Furthermore, the variation in the dose of the cationic polyDADMAC used with the coagulant FeCl3 can change the zeta potential of flocs (Bustamante et al, 2001, Keegan et al. (2009)).

If coagulation chemicals can be optimised without overloading the filters, it could save Sydney Water around $40 million by 2025-26 by avoiding the installation of four sedimentation tanks (currently planned for four WFPs operated by Sydney Water). Furthermore, for NOM removal, the plant typically removes 30 - 35% of the NOMs (as determined by dissolved organic carbon (DOC). Hence the need to maximise NOMs removal with the current water treatment chemicals and ensure disinfection by product limits are met.

The objectives of this study are three fold, namely:

- Develop a model to replicate the filter porosity and shear distribution in direct filters using Computational Fluid Dynamics (CFD).
- Design a device that reproduces the shear in the filters to experimentally quantify floc strength by identifying conditions that result in alteration of floc size and shape.
- Develop and construct a simple instrument that can rapidly detect changes in floc size and shape in the plant environment without the need for expensive particle size analytical equipment.
METHODOLOGY/PROCESS

The methodology comprises three stages, namely

Computational Fluid Dynamics Modelling of Full Scale Filters

In the first stage of the project a 3D Computational Fluid Dynamics (CFD) model (Figure 2) was developed to simulate the passage of floc through the filter medium. The accumulation of solids between backwashes reduces the pore volume over time. This increases the speed of fluid travelling through the filter which in turn increases the forces acting on the floc.

CFD simulations of a dual media filter used at Nepean WFP were developed in a micro-scale domain with various grain sizes. The SIMPLE (Semi-Implicit Method for Pressure Linked Equations) algorithm was used for pressure-velocity coupling and Second Order Upwind algorithm for discretization of the conservation equations (Figure 1a and b).

Design and manufacturing of the floc strength capillary device

In the second stage of the project, a novel capillary flow device was designed that reproduced the shear in the filters to test floc strength based on the CFD simulations (Figure 1). This involved making a tapered capillary that was 3 cm in length and 500 µm in diameter that was precision milled from a Perspex® block (Figure 3). By drawing floc suspensions through the device at flow rates of 10 to 30 ml/min, it was possible to achieve shear rates between 330 and 1560 s⁻¹.

Development of Floc Strength Instrument (FSI)

The instrument designed and constructed by Instrument Works combined both the capillary floc strength testing device and a custom dynamic image particle size analyser based on ISO13322-2 (Dyanamic Image Analysis Methods). The schematic of the instrument is shown in Figure 3.

The FSI specifications are as follows:

- Flow rate range to achieve shear rates that mimic Nepean filters: 0 – 50 ml/min.
- Minimum volume per test: 100 mL
- Measuring time: 5 -10 min
- Particle size detection range (approximately): 9 - 900 um
Testing of the Capillary Floc Strength (CFS) Device

Two types of “synthetic” flocs were prepared by adding fixed concentrations of ferric chloride solution and non-ionic polymer (LT20) and two concentrations of polyDADMAC, to humic acid solutions (TOC = 5-8 mg/L) buffered with NaHCO3 at pH 7.1.

At the time of testing, the CFS device the instrument had not yet been developed. Therefore, standard Master Sizer equipment was used to monitor the changes in particle size distribution of the flocs before and after subjected to the different shear rates.

DISCUSSION AND RESULTS ANALYSIS

Optimisation studies carried out at Nepean WFP concluded that floc strength is the predominant factor that reduced filter performance, leading to almost 40% reduction in plant capacity during heavy rain events (Mohiuddin et al, 2014). This is particularly serious after rain events when low turbidity and high colour reaches the plant.

Earlier attempts to characterise flocs in terms of their strength in the dynamic direct filtration process has been unsuccessful. Furthermore, research carried out by Jarvis et al. (2012) indicates no standard technique to determine floc strength in direct filtration is available.

Sydney Water initiated collaborative research with UNSW develop a technique to measure floc strength for plant operators to determine use when identifying the chemical treatment required to treat raw water with different quality in terms of coloured and uncoulored NOM.

Data analysis of filters at Nepean WFP.

Historical data was collected from 300 filtration cycles between 2012 and 2014.

Based on this, microscale simulations provided information on the pressure loss of the different filter material components, namely, coal (0.6 m deep; sand (0.3 m deep and gravel (0.2 m deep). The model was used to reproduce the head loss as a function of filtration time of the full scale filters. Thus the simulated head loss in the first 20 h of the filtration cycles correlated well with the operating data from the plant filters as seen in Figure 4 (Lian et al. 2016)

Testing of the Floc Strength Device Capillary

Synthetic flocs were subjected to different shear rates by feeding to the capillary tube (see Figure 2) at various flow rates.

Thus, at flow rates of 10, 20 and 30 mL/min., the Floc Strength Device can generate velocity gradients of 330, 990 and 1550 sec⁻¹. The effect of these three shear rates on the particle size distribution of synthetic flocs is shown in Figure 5.

Figure 4. Comparison between modelled and operational head loss

Figure 5. Effect of shear rate on the particle size distribution of synthetic flocs

Design and construction of Floc Strength Instrument (FSI)

The FSI was specifically designed for use at water treatment plants. The feed to the FSI can be <500 um flocs from either jar tests or from samples of coagulated water from the plant.

Based on the research carried out Instrument Works designed and constructed a stand-alone instrument built around the capillary device and incorporate an integrated image capture. The equipment also had data analysis capabilities. This allowed to replace the need to use external particle size analysis tools.
As a result, a simpler and portable fit-for-purpose instrument was constructed (Figures 6 and 7).

The components necessary to measure particle size distribution are as follows:

- The imaging system which includes a 5MP monochrome CCD camera sensor and a telecentric lens and illuminator system which provides rapid strobing of the LED backlight to accurately capture the particle size and shape.
- The liquid transfer system which includes a pump, the floc strength device and valves to all the capturing of the before and after images.
- One integrated on-board computer and touch screen to complete the image analysis, present the results to the user, and allow them to interact with the instrument.

The on-board computer analyses the floc images in real time and provides immediate feedback to the operator.

Currently, the analysis assumes flocs to be spheroidal. The particle size is therefore based on the identified area. The report provided by the FSI are (i) particle counts; (ii) mean particle size; (iii) standard deviation.

The evaluation of the floc strength is based on work by Jarvis et al., (2005) and determined by calculating the ratio of the mean particle size before and after the flocs being subjected to shear in the capillary device of the FSI. When breakage occurs, the ratio is expected to be less than one.

Data from the prototype units, shown in Figure 8, is currently being collected by Instrument Works to expand on the current analysis capabilities. It is expected that the instrument can be calibrated to other media filters through recalculation of the computational fluid dynamic modelling using data from existing filter designs.

CONCLUSION

- This paper describes the successful collaboration between Sydney Water – UNSW. The research outcomes were successfully implanted in the prototype instrument by Instrument Works within a six-month period of the research being completed.
- As result of this research project, Sydney Water now has an instrument that will enable Plant Operators to rapidly determine the effect of changes in water quality in terms of NOMs reaching its water filtration plants.
- Plant operators will now be able to adjust chemicals to treat raw water with changing
NOM compositions and maximise water production.

- This is a crucial innovation to assess the impact of water quality on flocs under conditions that mimic the dynamic conditions existing in filters. With this information, it should be possible to maximise plant capacity.

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REFERENCES


