Pre-Ozonation of Potable Water

Anna Möllergren

Department of Chemical Engineering 1, Lund Institute of Technology, Sweden and Hunter Water Australia

Abstract:
This study examines the suitability of pre-ozonation of potable water treatment at Grahamstown Water treatment plant. Pilot plant experiments were performed to investigate the effectiveness of pre-ozonation on coagulation of suspended colloids in the raw water. The removal of suspended particles was assessed through source water and filter effluent measurements of turbidity. In particular focus were the positive effects of ozone in various dosages, with and without the addition of alum, mainly by measuring turbidity, particle counts and colour. Other tests such as the zeta potential, pH, temperature, algae count, UV absorption (254, 455, 665 nm) and conductivity were measured for some of the samples. Following the examination of ozone influences on raw water, the study was extended to investigate filter run times and head loss build-up. The jar test method and pilot plant runs examined both conventional and direct filtration. Experiments carried out on this pilot plant have shown that pre-ozonation lead to a decrease in the particle count, colour and turbidity compared to the raw water. The ozone demand was 0.8 – 1.0 mg/L ozone.

Key words: Pre-ozonation; Ozone; Potable water; Destabilisation; Particle charge; Coagulation; Particle count

Introduction
All drinking water contains small concentrations of impurities, such as organic and inorganic compounds either in dissolved or in particular form. Treating water so that it meets drinking water standards for both appearance and safety can require many processes – coagulation, flocculation, sedimentation, filtration and residual disinfection. Each process is used to achieve a particular goal and any modification of a process to do double duty can be useful to water utilities. Coagulation may be such a process and therefore pre-ozonation of the raw water prior to coagulation was investigated.

Ozone (O$_3$) is a highly oxidizing molecule and has been proven to effectively disinfect water without creating dangerous disinfection by-products, which are formed when disinfecting water with chlorine [1]. Ozone may also have other positive influences on water treatment, such as improve the flocculation process by alterniating with the particle surface chemistry of particles present in the water. Oxidation is the break down of organic compounds into simpler molecules and complete oxidation converts an organic compound to carbon dioxide and water.

Most colloids (i.e. silica, kaolinite, aluminum) found in water have a negative charge due to the NOM (natural organic matter) sorption on the particle surface [2]. Stabilisation of colloidal particles in water is caused by this layer of absorbed organic molecules, which makes them repel one another and stay in dispersion due to electrostatic repulsion [3]. To coagulate these fine particles their electrical charge must be reduced or neutralised.

Ozone affects NOM in two ways; (i) oxidative cleavage of larger molecules and (ii) an increase in polarity because of an increase in acidic functional groups [2]. Ozonation may lead to desorption of humic materials from the particle surface, as a result of the increase in smaller molecules and the more polar carboxylic groups. The organic layer will decrease in thickness and the smaller, more polar groups will be less of a steric hindrance. This will allow the particles to come together and aggregate more easily [2].

Materials
Chemicals used in this project were Alum and Ozone. Dried and compressed air was used for ozone production. The alum used at Grahamstown was delivered as a liquid from a company called Omega Chemicals and contains approximately 50 % active ingredients i.e. Aluminium sulphate.

Method
Equipment
An Ozgen WT-10C ozonator was used to generate ozone gas by the “Corona discharge” method using air. A Confined Plunging Liquid Jet Contactor (CPLJC) was used to transfer the ozone gas into the water phase, see figure 1. The CPLJC introduced a jet of water through a nozzle into the cylindrical downcomer by the suction effect created. This generated fine bubbles, which travelled downwards with the water. The downcomer outlet was submerged in water in the riser, creating an airtight chamber. Most of the mass transfer took place in the mixing zone but also in the pipe flow zone [4]. Two different types of particle counters were used – MetOne Model PCX Online Particle Counting Sensors and a MetOne portable. Turbidity
measurements were made using Great Lakes online turbidity meters and a Hach 2100AN. Colour was manually measured against de-ionised water with the lowest detection limit of <5 Hazen Units (HU) at Grahamstown WTP lab.

Pilot Plant Facility

The investigation was performed at a permanent, two-line, pilot-scale facility located at Grahamstown Water Treatment Plant at Grahamstown, Newcastle (Australia). Each line of the pilot plant included a rapid-mixing tank, a flocculation basin with three compartments and a sand filter column. In the line with the CPLJC, ozone gas was drawn into the water pumped from the raw water tank and collected in an ozonation tank before pumped upstairs to a rapid mixing tank where alum was injected by a dosing pump. The water then entered the flocculation tank containing three cells, each with an independently driven motor and paddle with variable speed control to aid coagulation. The outgoing stream then entered the bottom of a clarifier and was drawn from below the water surface to a batch wise sand filter. The effluent was collected in a clear water storage tank and the filtered water was reused for sand filter back washing.

Experimental procedure

The experimental procedure consisted of jar testing, ozone demand tests and pilot plant runs. In particular focus for the investigation were the positive effects of ozone in various dosages, with and without alum, mainly by measuring turbidity (NTU), particle counts and colour. Other tests such as the zeta potential, pH, temperature, algae count, UV absorption (254, 455, 665 nm) and conductivity were measured for some of the samples. The impact of ozone on particle removal by settling and filtration was investigated using the jar test method at the pH of the raw water. The ozone demand of the raw water was determined by gradually increasing the ozone feed gas concentration until maximal ozone production occurred. The ozone demand is the point where a residual is measured in the water, meaning that everything that can be oxidized has been oxidized. Conventional water treatment was simulated in some pilot plant runs and direct filtration was also simulated, by letting the flow leaving the flocculation tank directly enter the sand filter. Only one line was used for some runs to get familiar with the equipment and to study the ozone induced changes of the raw water. The parallel lines were used when comparing the ozonated water and the raw water before and after sand filtration and to examine filter run times and head loss.

Results and Discussion

Jar Test

Results from jar tests confirmed that ozone has an effect on particle count and turbidity, especially particle count. A decrease in the raw water colour from 10-15 to <5 HU was observed and measured after ozone doses of about 0.3 mg/L without the addition of alum. Results presented from jar tests on filtered turbidity are referring to water filtered through a 0.45 µm paper filter.

It was observed during jar tests that, after the addition of alum, floc formed faster in the unozonated water jars than in the ones with ozonated water, especially for the jars with a higher alum dose. However, as seen in figure 2, the ozonated water resulted in lower settled turbidity than the unozonated samples for low alum doses (< 30 mg/L).

Filtered turbidity (see figure 3) indicated that a low dose of ozone improved the filtered turbidity compared to the raw water sample at alum doses over 20 mg/L.
Particle count on filtered raw and ozonated water is consistently lower for the ozonated samples when comparing water with the same alum doses (see figure 4).

Ozone Demand

Ozone demand tests showed that the residual concentration in the water increased with ozone dose and the consumed ozone was 30–45 % of the generated ozone. The ozone demand presented in figure 5 was between 0.8–1.0 mg of O₃ per litre of Grahamstown raw water. The consumed ozone stayed rather stable after an ozone residual was measured in the water since everything that could be oxidised in the water was oxidised.

Pilot Plant Run

As seen in figure 7, the particle count of the sand filtered water decreased soon after ozone production was initiated and increased when ozone production was stopped. Also observed in figure 7, was the increase in particle count of the filtered water in the end of the run. Runs were stopped and filters were back-washed when turbidity and particle breakthrough occurred.

The decrease in turbidity due to ozone is harder to determine than the decrease in particle count, as seen in figure 8. Both runs (one line with ozone and the other with raw water) had the same alum dose and showed similar results in filtered turbidity. However, soon after the start of the runs, it was obvious that the head loss build-up was slower for the ozonated run compared to the raw water. This means that the filters will run for a longer time and will need to be back-washed less frequently, which is obviously desirable.
Results from UV absorbance measurements, conductivity and the zeta potential did not result in any conclusions of the ozone effect on particle chemistry since there was little change from the raw water results. The algae counts showed little change of the ozone dosages 1.0 – 1.5 mg/L. Raw water turbidity, particle count, pH, colour and temperature stayed stable relatively stable throughout the experiments.

Conclusions
The Pilot Plant study results cannot be summarised with one ozone dose and one alum dose that would give the best results. The effects of pre-ozonation are likely to vary with the nature of source water and other factors. Carefully controlled pilot studies with parallel treatment lines are needed to further determine the overall impact of pre-ozonation on performance of the various stages of potable water treatment. Results from this study are as following:

- An ozone dose over 0.3 mg/L of Grahamstown water will decrease the raw water particle count by at least 20% without the addition of alum.
- An ozone dose over 0.5 mg/L of Grahamstown water will decrease the apparent colour of the raw water from 10-15 down to <5 Hazen Units without the addition of alum.
- For the more part of samples, an ozone dose > 0.5 mg/L of Grahamstown water will lower the raw water turbidity.
- Turbidity measurements showed that ozonation improved the settling of floc at low alum doses (<30 mg/L).
- The optimum ozone demand dose is 0.8 – 1.0 mg/l of Grahamstown water.
- Ozonation of water with addition of alum lead to smaller and also slower floc formation compared to the floc formed in raw water with only alum.
- Smaller size floc lead to a longer head loss build-up time and a more even distribution of the floc in the filter media.
- An ozone dose between 0.5-1.0 mg/L combined with an alum dose of at least 30 mg/L gave the best results over-all in turbidity, filtered turbidity and particle count.

Acknowledgments
My supervisors, Prof. Geoffrey Evans at School of Engineering, University of Newcastle, Craig Jakubowski and Artur Majerowski at Hunter Water Australia, and Prof. Anders Axelsson at the department of Chemical engineering 1, Lund Institute of technology are gratefully acknowledged for their help, support and guidance. I would also like to thank Peter Dennis and Darren Bailey at Hunter Water Australia for the opportunity to write my diploma thesis at Grahamstown Water Treatment Plant. I extend my thanks to Dave Kingsland for performing chemical analyses and useful advice on various problems.

Abbreviations
CPLJC = Confined plunging liquid jet contactor
DBP = disinfection by-products
HU = Hazen Unit
NOM = natural organic matter
NTU = nephelometric turbidity units
UV = ultraviolet radiation
WTP = water treatment plant

References