

Removal of ammonia from drinking water by biological nitrification in a fixed film reactor

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SUMMARY

The absence of water catchment protection often results in contamination of drinking water supplies. Waters in South East Asia have been exploited to support extensive agriculture, industry, power generation, public water supply, fisheries and recreation use. Ammonia has been identified as a significant contaminant of drinking water because of its ability to affect the disinfection efficiency of chlorine. The interference of ammonia with chlorination is a prevalent and expensive problem faced by many water treatment plants (WTPs) located throughout South East Asia. The conventional approach for ammonia removal was to pre-chlorinate using high concentrations of chlorine, which has a number of disadvantages including the formation of disinfection by-products and high chlorine consumption.

This thesis investigated the application of high rate nitrifying trickling filters (NTFs) as a means of ammonia removal from a polluted lowland water source as an alternative to pre-chlorination. NTFs are widely used for the biological remediation of ammonia rich *wastewater*, however their performance when required to operate under low ammonia concentrations for *potable water* applications was unknown.

A NTF pilot facility consisting of one large-scale, and three small-scale NTFs were constructed at Hope Valley WTP in South Australia. The NTFs were operated to simulate the raw water quality of a polluted catchment identified in Indonesia (Buaran WTP), including variations in ammonia, biological oxygen demand (BOD₅), and turbidity. Results confirmed that plastic-packed NTFs were able to operate equally successfully under low ammonia-N concentrations, some 10- to 50-fold lower than that of conventional wastewater applications, where complete conversion of ammonia to nitrate was consistently observed under these markedly reduced loadings. Results also showed that when operated under mass loads equivalent to typical ammonia loading criteria for wastewater NTFs, by increasing hydraulic flow, comparable apparent nitrification rates were achieved. These results confirmed that mass transport limitations posed by low ammonia-N concentrations on overall filter performance were insignificant.

This thesis also investigated the impact of organic carbon quantity and biodegradability on the nitrification behaviour of the pilot NTF. Results demonstrated that organic carbon loading, rather than the C:N ratio, was an important regulator of filter nitrification capacity, where a linear decline in nitrification performance correlated well with sucrose and methanol augmented

carbon loads. Extensive monitoring of inorganic nitrogen species down the NTF, to profile nitrification behaviour, showed sucrose-induced carbon loads greater than $870 \text{ mg sBOD}_5 \text{ m}^{-2} \text{ d}^{-1}$ severely suppressed nitrification throughout the entire filter bed. This study also confirmed that critical carbon loads for nitrification varied among carbon sources. In contrast to sucrose, when a more native-like carbon source was dosed (organic fertiliser), no significant decline in nitrification capacity was observed. This could be attributed to differences in carbon biodegradability.

This research has provided new insights into the microbial ecology of a potable water NTF. The combination of fluorescent *in situ* hybridisation (FISH) and scanning electron microscopy (SEM) for *in situ* analysis of biofilms was successful in identifying the spatial distribution of ammonia oxidising bacteria (AOB), nitrite oxidising bacteria (NOB) and heterotrophs. When the NTF was operated under low organic loads, clusters of AOB and NOB were abundant, and were located in close proximity to each other. Uniquely, the study identified not only *Nitrospira* spp but also the less common *Nitrobacter* spp within the NTF biofilm. Biofilm analysis showed that the type of carbon source also strongly influenced the biofilms characteristics in terms of biomass ecology, morphology, and polysaccharide composition, which was correlated with NTF performance. Results showed that an increase in sBOD_5 via the addition of sucrose promoted the rapid growth of filamentous heterotrophic bacteria and production of large amounts of polysaccharide. Stratification of nitrifiers and heterotrophs, and high biofilm polysaccharide concentrations were observed at all filter bed depths, which coincided with the impediment of nitrification throughout the entire filter column. High biofilm polysaccharide concentrations also coincided with a significant increase (40 %) in filter hydraulic retention time, as determined by hydraulic tracer experiments. In contrast to sucrose-fed biofilms, organic fertiliser-fed biofilms had a more uniform and dense ultra-structure dominated by many rod shaped bacteria, and was significantly lower in polysaccharide composition. This observation was coupled with superior nitrification performance.

This study confirmed that a well functioning NTF is a viable, low cost alternative for ammonia removal from source water abstracted from poorly protected catchments found in many developing countries. Pre-treatment using NTFs has the potential to reduce the chlorine dose required for pre-chlorination. Thereby improving water quality by minimising the formation of disinfection by-products, and improving the control of chlorination. NTFs could also find ready application in other situations where ammonia interferes with chlorine disinfection.

DECLARATION

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for any degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

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Abbreviations

Ammonia-N- ammonia-nitrogen
AOB- ammonia oxidising bacteria
BAF- biological aerated filter
BNR- biological nutrient removal
BOD₅- total 5 day biological oxygen demand
CFU- colony forming units
COD- chemical oxygen demand
DAPI- 4',6-diamidino-2-phenylindole
DO- dissolved oxygen
DOC- dissolved organic carbon
EDTA- ethylenediamine tetra-acetate dihydrate
EPS- extracellular polysaccharide
FISH- fluorescent *in situ* hybridisation
HPC- heterotrophic plate count
HRT- hydraulic retention time
Nitrate-N- nitrate-nitrogen
Nitrite-N- nitrite-nitrogen
NOB- nitrite oxidising bacteria
NO_x- oxidized nitrogen (nitrite-N + nitrate-N)
NTF- nitrifying trickling filter
NTU- Nephelometric turbidity units
PAC- powdered activated carbon
PBS- phosphate-buffered saline
PVC- polyvinylchloride
RFL- relative fluorescence
RNA- ribonucleic acid
rRNA- ribosomal ribonucleic acid
 r_s - Spearman's correlation coefficient
RTD- residence distribution curve
sBOD₅- soluble 5 day biological oxygen demand
SD- standard deviation
SEM- scanning electron microscopy or scanning electron micrograph
SS- suspended solids
TOC- total organic carbon
WTP- water treatment plant
WWTP- wastewater treatment plant