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Tertiary treatment and dual disinfection to improve microbial quality of reclaimed water for potable and non-potable reuse: A case study of facilities in North Carolina

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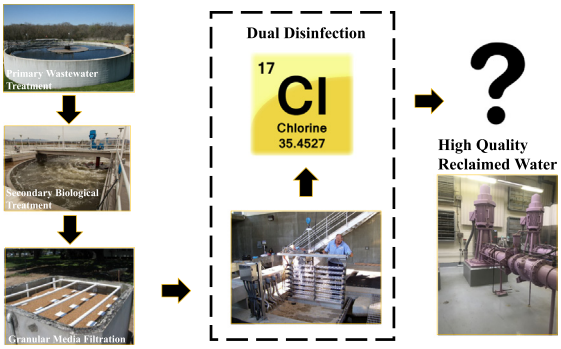
HIGHLIGHTS

- A case study on dual disinfection treatment of wastewater to produce high quality reclaimed water.
- Fecal indicator organisms and pathogens were reduced using non-membrane treatment methods.
- Concentrations of adenovirus were detected by both qPCR and by ICC-qPCR.

GRAPHICAL ABSTRACT



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ABSTRACT

Treated wastewater is increasingly of interest for either nonpotable purposes, such as agriculture and industrial use, or as source water for drinking water supplies; however, this type of advanced treatment for water supply is not always possible for many low resource settings. As an alternative, multiple barriers of physical, chemical and biological treatment with lower cost and simpler operation and maintenance have been proposed as more globally applicable. One such water reclamation system for both non-potable and potable reuse, is that approved by the State of North Carolina "for Type 2" reclaimed water (NCT2RW). NC Type 2 potable reuse systems consist of a sequence of tertiary treatment to produce well oxidized reclaimed water that is then then further treated by two steps of disinfection, typically UV radiation and chlorination. In this case study, the log10 microbial reduction performance of NCT2RW producing water reclamation facilities is evaluated. Based on the results presented here, NCT2RW consistently achieved high (6 for bacteria, 4 for virus and 4 for protozoan parasite surrogates) log10 reductions using the NC proposed treatment methods. Additionally, lower but significant log10 reduction performance was also documented for protozoan parasites and human enteric viruses.

1. Introduction

With increasing pressure from population growth, water scarcity and climatic variability, there is interest in alternative water sources to

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augment the current drinking water supply (NAS, 2012; WHO, 2017). Treated wastewater is increasingly used for either non-potable purposes, such as agriculture and industrial use, or as source water for drinking water supplies, either unplanned as upstream wastewater discharges reaching water supply intakes or by purposeful use of engineered water reuse systems (ATSE, 2017; NC DENR, 2011; WHO, 2017). Potable reuse involves the use of treated wastewater as either a supplement to the drinking water supply (indirect reuse) or as the water supply itself (direct reuse). The reuse of reclaimed wastewater has many advantages for protecting the environment and human health by managing the water resources of the hydrologic cycle in order to minimize the degradation of water, land and the built environment by anthropogenic activities.

Indirect potable reuse has been widely practiced globally for many decades as "*de facto*" reuse of untreated and treated wastewater discharged to surface water and aquifers for downstream drinking water sources and supplies and as planned, designed and managed indirect potable reuse using engineered treatment systems. Direct potable reuse using engineered treatment systems became a reality as early as 1968 in Namibia, with other countries such as Singapore, South Africa and the USA later leading the way with direct potable reuse schemes and technologies (Brandhuber et al., 2015; WHO, 2017).

Direct potable reuse of reclaimed wastewater typically includes the use of more complex and expensive wastewater treatment technologies, such as membrane filtration with micro-, ultra-, nano and reverse osmosis filters. However, this type of advanced treatment for water supply is not always possible for many low resource settings. Therefore, multiple barriers of alternative physical, chemical and biological treatment technologies with lower cost and simpler design, operation and maintenance have been proposed as more globally applicable. One such water reclamation system for both non-potable and potable reuse, is that approved by the State of North Carolina "for Type 2" reclaimed water (NCT2RW). NC Type 2 potable reuse systems consist of a sequence of tertiary treatment processes to produce well oxidized reclaimed water that is then further treated by two steps of disinfection, typically UV radiation and chlorination. As for all water reclamation systems used for beneficial purposes, achieving extensive microbial pathogen reductions to produce water with acceptably low risk from infectious diseases is considered essential (ATSE, 2017; NAS, 2012; WHO, 2017). In order to document microbial pathogen reductions, the NC reclaimed water treatment scheme uses fecal indicator-based microbiological performance criteria. The regulation specifies $\log_{10}$ reductions from initial raw sewage concentrations of 6 for *E. coli* bacteria, 5 for coliphage viruses and 4 for *Clostridium perfringens* as a protozoan parasite surrogate. Effluent quality for NCT2RW must also meet a geometric mean concentration limit of ≤3/100 mL for *E. coli* and ≤5/100 mL for both coliphages and *Clostridium perfringens*, with daily maxima of 25/100 mL for each of these three target microbe types. This tertiary treated, dual disinfected reclaimed water can be blended with surface water at a ratio of no >20% reclaimed/80% surface water, held for 5-days of protected storage, and then subjected to conventional drinking water treatment to produce potable water.

As there is increasing interest in and implementation of both non-potable and potable reuse, there is a need to evaluate simple and low cost alternatives to membrane treatment technologies that also may be capable of producing high quality reclaimed water. The focus of this study is to measure and compare the concentrations of indicators and pathogens in influent raw sewage and the finished tertiary treated and dual disinfected reclaimed water produced by four NC water reclamation facilities. The goal is to determine if these facilities meet the $\log_{10}$ microbial reduction performance standards and target reclaimed water microbial concentrations for 1) the fecal indicators mandated by NC regulation (*E. coli*, coliphages and *C. perfringens*) and 2) enteric pathogens that these indicators are intended to represent, specifically, *Salmonella* spp. bacteria, human enteric viruses (Adenoviruses, and Noroviruses), and the protozoan parasites *Cryptosporidium* and *Giardia*. It is noted that none of the four treatment facilities studied are as yet certified by the State of NC to produce NCT2RW, even though they have the specified multi-barrier treatment trains to qualify for seeking such certification.

2. Materials and methods

2.1. Water samples

Four water reclamation facilities located in central NC that have treatment systems capable in principle of producing tertiary treated dual disinfected "Type 2" reclaimed water were sampled bimonthly for raw sewage and dual disinfected RW for 1 year. Dual disinfected reclaimed water samples were treated by primary wastewater treatment followed by either activated sludge or mixed anaerobic/aerobic activated sludge processes, secondary clarification, granular media filtration and finally dual disinfection. Disinfection was a two-step system of 1) ultraviolet light at a dose of 30 mW/cm^2 and 2) sodium hypochlorite dosed to achieve a final total chorine residual of 2–3 mg/L. All plants are required to meet State of NC standards for fecal coliform bacteria concentrations in their discharged treated effluents. However, none were certified by the State to produce NCT2RW.

Grab samples of raw sewage and final reclaimed water effluent were taken using approved techniques (Standard Methods for the Examination of Water and Wastewater; SMEWW). At each plant 200 mL of raw sewage and 12 L of dual disinfected RW were collected and split into two volumes, one for pathogen analysis and one for indicator analysis.

2.2. Sample processing and concentration methods

Primary concentration for viruses and parasites in reclaimed water samples was performed using hollow fiber ultrafiltration (HFUF) and elution by the method of Hill et al. (2007) and Polaczyk et al. (2008). Fig. 1 shows the reclaimed water sample processing procedures. Briefly, 10 L of dual disinfected RW was spiked with a commercially available positive internal control for protozoan parasites (uniquely fluorescently labeled *Giardia* and *Cryptosporidium* (oo)cysts (BTF Precise Microbiology, Inc., Pittsburgh, PA) and filtered through the Fresenius Optiflux F250NR hollowfiber ultrafilter. Water samples were concentrated to produce a retentate volume of approximately 100-200 mL, and ultrafilters were backflushed with a solution containing 0.5% Tween 80, 0.01% sodium polyphosphate (NAPP) (Sigma-Aldrich, cat# 305553-25G), and 0.001% Antifoam Y (Sigma-Aldrich, cat# A5758-100 mL). The backflush liquid was added to the retentate liquid to produce a total concentrate volume of approximately 200-250mLs. The resulting concentrate was subjected to a series of centrifugation and elution steps to separate viruses from protozoan parasites. First, the concentrate was centrifuged (1,500 ×*g*, 30 min,4 °C) to separate it into a pellet (containing viruses and protozoan parasites), and a virus-containing supernatant.

The virus containing supernatant was centrifuged a second time (5000 ×*g*, 30 min, 4 °C). The pellet from this second centrifugation was eluted with 0.5 M pH 7.5 threonine for 1 h with mixing at 60RPM and then centrifuged a third time (5000 ×*g*, 30 min, 4 °C). The threonine-elution supernatant from this third centrifugation was then combined with the supernatant from the second centrifugation.

The pellet from the initial low speed centrifugation was eluted using 0.5 M pH 7.5 threonine for 1 h at room temperature with mixing at 60RPM to release any viruses that might have been present in it. The threonine eluate was re-centrifuged (1,500 ×*g*, 30 min, 4 °C) to concentrate protozoan parasites in the pellet, and the virus-containing threonine eluate supernatant was collected and combined with the virus-containing supernatants from the processing steps described above.

For raw sewage, a 200 mL sample was centrifuged at 1,500 ×*g* for 30 min to separate into a parasite-containing pellet and virus-