Science of the Total Environment 529 (2015) 275–284

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Dishwashing water recycling system and related water quality standards for military use

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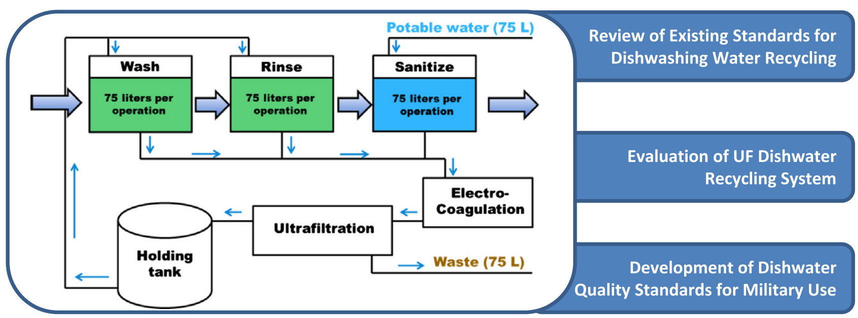
HIGHLIGHTS

- A compact ultrafiltration system was developed for field dishwashing water reuse.
- A review was conducted to recommend standards for dishwashing water reuse.
- A specific dishwashing water reuse standard was developed for military use.
- The water standard was cross-evaluated by monitoring reclaimed dishwashing water.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 6 March 2015
Received in revised form 29 April 2015
Accepted 3 May 2015
Available online xxxx

Editor: D. Barcelo

Keywords:
Dishwashing water
Greywater
Military use
QMRA
Recycling
Water quality standard

ABSTRACT

As the demand for reliable and safe water supplies increases, both water quality and available quantity are being challenged by population growth and climate change. Greywater reuse is becoming a common practice worldwide; however, in remote locations of limited water supply, such as those encountered in military installations, it is desirable to expand its classification to include dishwashing water to maximize the conservation of fresh water. Given that no standards for dishwashing greywater reuse by the military are currently available, the current study determined a specific set of water quality standards for dishwater recycling systems for U.S. military field operations. A tentative water reuse standard for dishwashing water was developed based on federal and state regulations and guidelines for non-potable water, and the developed standard was cross-evaluated by monitoring water quality data from a full-scale dishwashing water recycling system using an innovative electrocoagulation and ultrafiltration process. Quantitative microbial risk assessment (QMRA) was also performed based on exposure scenarios derived from literature data. As a result, a specific set of dishwashing water reuse standards for field analysis (simple, but accurate) was finalized as follows: turbidity (<1 NTU), *Escherichia coli* (<50 cfu mL^{-1}), and pH (6–9). UV_{254} was recommended as a surrogate for organic contaminants (e.g., BOD_5), but requires further calibration steps for validation. The developed specific water standard is the first for dishwashing water reuse and will be expected to ensure that water quality is safe for field operations, but not so stringent that design complexity, cost, and operational and maintenance requirements will not be feasible for field use. In addition the parameters

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http://dx.doi.org/10.1016/j.scitotenv.2015.05.007

can be monitored using simple equipment in a field setting with only modest training requirements and real-time or rapid sample turn-around. This standard may prove useful in future development of civilian guidelines.

1. Introduction

The demand for reliable and safe water supplies for municipal, agricultural, industrial, and military use has been continuously growing over the last few decades with population growth, economic development, climate change, and depletion of traditional freshwater supplies (USEPA, 2012). Greywater is used water from bathroom and kitchen sinks, showers/bathtubs, and laundry facilities (Scholze and Page, 2011) and is typically reused as irrigation and toilet flushing in urban settings. Greywater reuse has attracted a great amount of attention as a water conservation strategy and many greywater reuse systems have been developed and implemented in commercial and residential facilities to achieve significant water savings indoors and outdoors (Yu et al., 2013). However, in remote locations of limited water supply, like those encountered in military installations, greywater applications are expanded to showering and firefighting. For these remote places, it is desirable to expand potential uses to include the recycle of dishwashing water to maximize the conservation of fresh water. This study seeks to develop a specific water reuse standard for a dishwashing water recycling system for military field operations in fresh water-limited locations and to validate the developed water standard by cross-evaluating the water quality data from a greywater recycling system. For the current scope of work, this study will focus on water reuse within the United States (U.S.) Military, however the results of this study may be applicable for a number of other settings involving traveling individuals in remote and water-scarce locations, such as Peace Corps volunteers.

For the reuse of greywater in the U.S., many regulations and standards have been developed based on the U.S. Environmental Protection Agency (USEPA) Secondary Treatment Standard. Water quality standards for greywater reuse should satisfy the following four criteria: hygienic safety, esthetics, environmental tolerance, and economic feasibility (Nolde, 2000). Typical greywater standards are regulated at the state level and exclude greywater generated from dishwashing because of the relatively large concentration of pollutants (USEPA, 2012; Friedler, 2004; Li et al., 2009). However, these standards vary from state to state and there are currently no guidelines or regulations regarding dishwashing water recycling at either the federal/state level or in the U.S. Army Public Health Command (USAPHC) guidelines (USAPHC, 2011). Guidelines for water reuse in military field operations set by U.S. Army Technical Bulletin TB MED 577: "Sanitary Control and Surveillance of Field Water Supplies" differ from state-regulated standards and include standards for shower and laundry water recycling (US Army, Navy, and Air Force, 2010); but there were no standards for dishwater recycling. The gap between state greywater regulations and military guidelines, along with the lack of guidelines for dishwater reuse standards make the deployment of a dishwater recycling system difficult (Lazarova et al., 2003).

Given the need to further develop military guidelines for dishwater recycling, the objective of this paper is to recommend standards for the use of reclaimed dishwashing water, based on federal, state, and USAPHC regulations and guidelines for non-potable water use. Water quality data (e.g., BOD_5, COD, TOC, pH, Turbidity, TSS, TDS, TP, UV_{254}, and SUVA) from a full-scale dishwashing water recycling system using electrocoagulation (EC) and ultrafiltration (UF) were evaluated, and the chlorine demand and disinfection by-product formation potential (DBPFP) of chlorinated treated dishwashing water were assessed. A quantitative microbial risk assessment (QMRA) model was used to develop recommendations for the maximum tolerable concentrations of *Escherichia coli*, *Salmonella*, and human norovirus in reclaimed dishwashing water.

2. Materials and methods

2.1. Evaluation of dishwater treatment device

2.1.1. Ultrafiltration dishwashing water recycling system

A full-scale prototype of the dishwashing recycling system was constructed and operated by Mainstream Engineering Corporation (Rockledge, FL, USA) for a year (Fig. 1) (Amundsen et al., 2013). Water collected from three 76 liter sinks (wash, rinse and sanitize) was first treated by electrocoagulation using zinc electrodes to destabilize emulsions and precipitate suspended particles from the high-pH greywater (due to detergents used in dishwashing). Then the water was further processed by ultrafiltration using a hollow fiber, cross-flow, modified polyethersulfone membrane (WaterSep, Marlborough, MA, USA) with a molecular weight cutoff of 750 kDA (Amundsen et al., 2013). A standard issue powdered detergent (NSN 7930-00-281-4731, NuGentec, Emeryville, California) was supplied as a detergent and a preliminary analysis showed that the detergent's pH was 9.4 and includes sodium phosphate derivative anionic surfactant (Fig. S1). The electrocoagulation system was constructed with PVC with dimensions of 27 cm (H) × 5 cm (L) × 6 cm (W). The electrodes were constructed with zinc measuring 27 cm (H) × 5 cm (L) × 0.3 cm (W) and were separated by 0.6 cm. The seven electrode plates were put in the cell with one electrode as the anode, one electrode as the cathode (the anode and cathode were located at opposite ends of the reactor) and five inner plates operating in a bipolar fashion. The total electrode area was 810 cm^2 with an applied potential of 20 V (AC). The current density was 1.85 mA/cm^2 and the cell residence time was 7 min. The UF membrane was operated at 25 °C with a transmembrane pressure of 0.10 MPa and a feed flow rate of 400 mL/min. The filter was backflushed for 30 s every 3 min at 0.14 MPa using permeate. The filter was also cleaned, alternating between white vinegar and 1.0 M NaOH, for 10 min for every 4 h of runtime. Samples were collected weekly for testing.

A synthetic surrogate dishwashing water used during the system operation as a representative sample of US Army field dishwashing effluent. Concentrated food mixture (3 kg baked beans, 1.28 kg chili con carne and 1.9 L of water) (8.3 mL), vegetable oil (2.5 mL) and NSN 7930-00-281-4731 dishwashing soap (20.0 g) were combined with 3.79 L (1 gal) of fresh tap water to produce the synthetic greywater with a BOD_5 of 1000 mg/L and TSS of 850 mg/L (Natick Soldier Center, 2007).

2.1.2. Water quality analysis

On-site samples were collected weekly from the dishwater recycle device at 25 °C and analyzed in the UCF laboratories within 3–6 h. Sample collection was performed in accordance with Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, and WEF, 1998). Water quality analyses were performed in accordance with Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, and WEF, 1998). The parameters measured included biological oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), total phosphorus, pH, temperature, total organic carbon (SM 5310), UV_{254} (EPA 415.3), SUVA (EPA 415.3), trihalomethanes (THMs) (SM 6232 B), and haloacetic acids (HAAs) (EPA 552.2). HAAs were analyzed by a certified