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Feasibility, safety, and economic implications of whey-recovered water in cleaning-in-place systems: A case study on water conservation for the dairy industry

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ABSTRACT

Water scarcity is threatening food security and business growth in the United States. In the dairy sector, most of the water is used in cleaning applications; therefore, any attempt to support water conservation in these processes will have a considerable effect on the water footprint of dairy products. This study demonstrates the viability for recovering good quality water from whey, a highly pollutant cheese-making by-product, to be reused in cleaning-in-place systems. The results obtained in this study indicate that by using a combined ultrafiltration and reverse osmosis system, 47% of water can be recovered. This system generates protein and lactose concentrates, by-products that once spray-dried fulfill commercial standards for protein and lactose powders. The physicochemical and microbiological quality of the recovered permeate was also analyzed, suggesting suitable properties to be reused in the cleaning-in-place system without affecting the quality and safety of the product manufactured on the cleaned equipment. A cost analysis was conducted for 3 cheese manufacturing levels, considering an annual production of 1, 20, and 225 million liters of whey. Results indicate the feasibility of this intervention in the dairy industry, generating revenues of $0.18, $3.05, and $33.4 million per year, respectively. The findings provide scientific evidence to promote the safety of reuse of reconditioned water in food processing plants, contributing to building a culture of water conservation and sustainable production throughout the food supply chain.
Key words: water reconditioning, water optimization, food industry, membrane filtration

INTRODUCTION

Water and food production have such inextricable relation that water scarcity is adversely affecting US agriculture with potential implications for decreasing the food supply and raising food prices (USDA, 2014a). Water shortages and the effect of climate change are risk factors for food security along with the increasing population estimated to reach 9 billion people by 2050 (de Fraiture and Wichelns, 2010). Therefore, water availability for food production will increasingly rely on the sustainable management and use of water in all sectors.

Detailed data on water usage in US dairy processing are not widely available. Nevertheless, published reports from other countries, where water scarcity became a top priority years ago (e.g., Australia), indicate that food industry alone is responsible for 30% of water consumption in all manufacturing combined (Australian Government Department of Agriculture, Fisheries and Forestry, 2008). Food processing uses only high-quality fresh water as an ingredient and for processing steps such as washing, cooling, heating, transportation, and cleaning. The amount of water used in a particular food processing plant varies depending on the size, efficiency of the equipment, plant layout, and culture. The dairy industry uses 1 to 60 L of water per kg of processed milk, mainly for cleaning-in-place (**CIP**) applications (28% of total water usage; Rad and Lewis, 2014).

Proper reconditioning (treatment of water intended to be reused) and reuse of wastewater in the food industry is a promising alternative to current practices of discharging these streams in places where they can negatively affect the environment. The authors firmly believe that wastewater recondition, using technologies already available for the food industry, can contribute to conservation initiatives without compromising the safety and the quality of the final product.

Current regulations on food hygiene indicate that only potable water can be used for food contact surfaces and equipment cleaning (FDA, 2013; Codex

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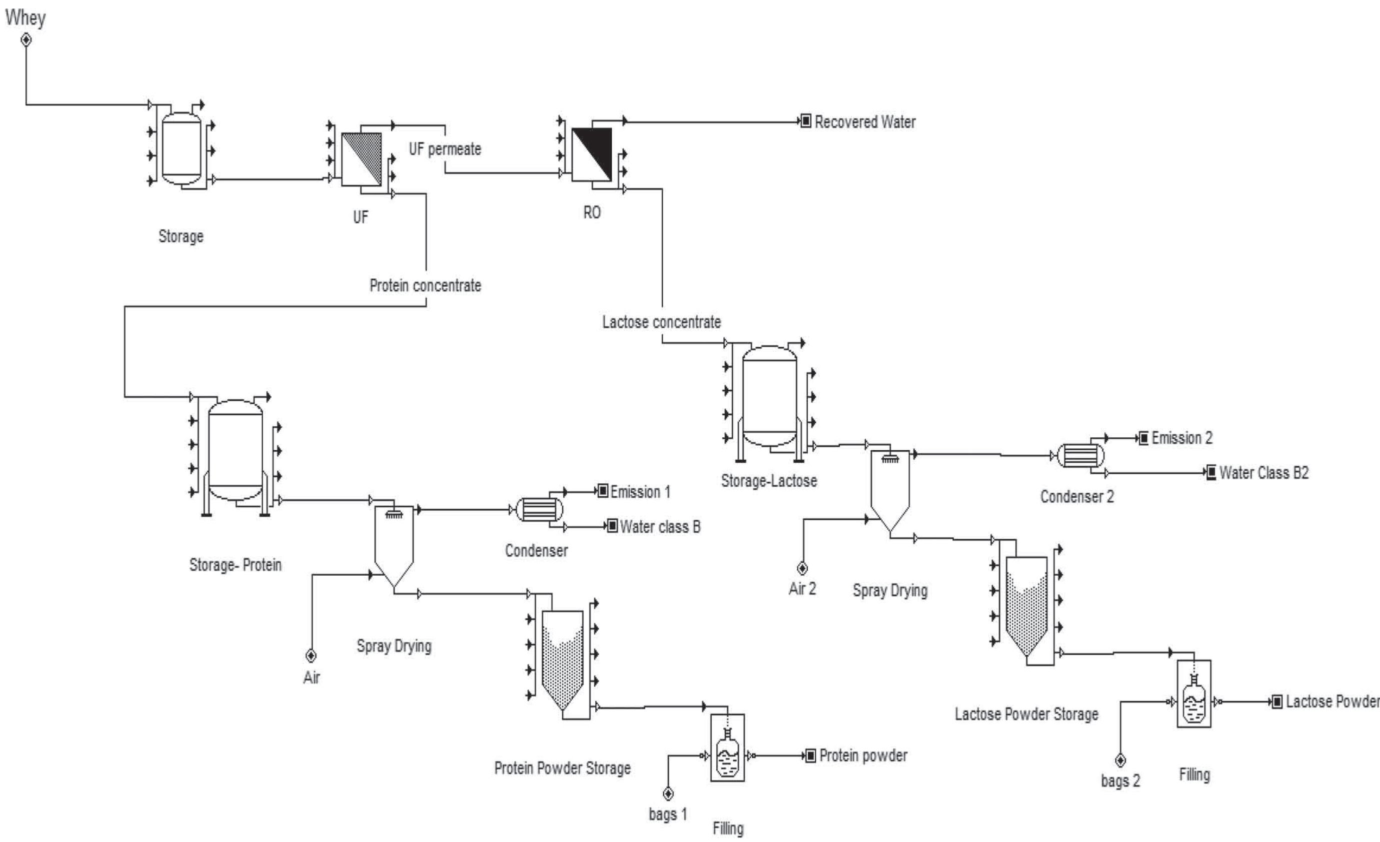

Figure 1. Water recovery system using UF/reverse osmosis (RO) membranes with protein and lactose powder production. Water class B and B_2 (condensed water obtained during the spray drying steps), emission 1 and 2 (air leaving the spray drying system).

Alimentarius, 2014), whereas the use of reconditioned water is restricted to initial cleaning of vegetables and fruits, and to the scalding water for meat and poultry (USDA-FSIS, 2012). However, processors are willing to expand the applications for reconditioned water to reduce the consumption of this natural resource and minimize environmental impacts (Casani and Knøchel, 2002).

The lack of published data about the implications of using reconditioned water in food processing plants represents a barrier for water recycling; such information is key to motivate implementation of water conservation initiatives. For that reason, the present study was developed as a holistic approach to provide evidence on the advantages and restrictions of wastewater recondition and reuse; based on the 3 pillars of sustainability (economic, environmental, and social). The main objective was to demonstrate that high quality water can be recovered from cheese whey, with potential for water reuse in CIP operations. First, the performance of the UF and reverse osmosis (**RO**) system was evaluated based on permeate flux, pressure changes, volume reduction ratio, flux decline, filtration time, rejection, and retentate solid content. The cleaning efficiency of the recovered water versus potable water was assessed, and finally a cost analysis, for different cheese production scales, was considered to evaluate the feasibility of this proposed approach in the dairy industry. A diagram of the water recovery system and whey powder production is presented in Figure 1.

MATERIALS AND METHODS

Water Recovery System Configuration and Operating Conditions

Membrane Filtration. Cheddar cheese whey, produced from standardized whole milk (3.6% fat), was collected from 3 different cheese batches (276.5 ± 11 L each time). Whey was collected from a processing plant located in Lincoln, Nebraska, throughout September and October of 2014. Once collected, the whey was immediately fed to the filtration system to avoid additional heating or pH changes (initial temperature 33 ± 2°C). The UF and RO filtrations were performed in the model R pilot scale membrane filtration system