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Adjustment of the wastewater matrix for optimization of membrane systems applied for water reuse in breweries

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ABSTRACT

The objective of this study was to optimize membrane systems applied for wastewater reuse in breweries in consideration of economic efficiency and safety of operation by defining and adjusting the wastewater matrix. With the help of extensive quantitative and qualitative analyses of relevant process water flows from several breweries with similar product ranges and different wastewater treatment concepts, the following process water flows were identified as critical regarding membrane filtration: polyvinylpolypyrrolidone regeneration lye, cleaning and rinsing lyes from cleaning in place systems as well as effluents from the bottle washing machine and conveyor belts. Their negative effects on the filtration performance of low pressure membranes were shown in laboratory-scale tests. In addition, treatment concepts of recycling the alkaline process water flows (polyvinylpolypyrrolidone regeneration lye, cleaning in places lyes) were developed and investigated with regard to technical, ecological and economic aspects. As secondary objectives, the reduction of inert organic substances, the recovery of valuables (polyphenols, sodium hydroxide solution) and the substitution of critical substances (lubricants for conveyor belts) were pursued.

1. Introduction

Due to rising water and wastewater costs or limited supply and quality of fresh water, the stewardship of the resource “water” is becoming increasingly important for the brewing industry. In addition to a cleverly chosen water management system, the treatment of the total effluent (end-of-pipe) and the treatment of process water flows are already the focus of several research projects and technical applications [1–7].

Thereby, the motivations for wastewater reuse may be different. One good reason for it is to reduce production costs or to keep them on a constant level. The tightening of conditions for direct and indirect discharge of wastewater can be another one. Furthermore, if fresh water supply is limited, a carefully selected reuse with an advanced wastewater treatment can lead to additional production capacity and therefore economic benefits.

Especially in countries with comparatively high water costs, wastewater recycling can have monetary advantages as it is proven by the following model calculation. The specific water consumption of a modern brewery (without water recycling plant) amounts to 4 L/L sold beer (SB) depending on the individual production conditions (Fig. 1); the resulting wastewater amount averages 2.2 L/L SB although the range of variations is very large [8]. Therefore, a medium-scale brewery with an annual beer output of 100,000 m^3 requires 400,000 m^3/year fresh water and produces 220,000 m^3/year wastewater. Calculating with a fresh water price of 2.20 €/m^3 and a wastewater price of 2.50 €/m^3 for Berlin region, even modern breweries have to bear annual water costs of 1.4 million €. Considering that up to 30% of fresh water used for processes without product contact (e.g. external rinsing and cleaning processes, cooling towers or boiler feeding) can be substituted by recycled water [9], significant cost savings in breweries are possible by wastewater recycling.

On the other hand, this is accompanied by the costs for wastewater treatment which are a function of plant structure and scale. The operating costs (exclusive of personnel) of a membrane bioreactor followed by nanofiltration can be calculated with 1.35 €/m^3 wastewater [11]. It can be followed that the annual treatment costs amount to 337,000€ related to the model brewery mentioned in the previous paragraph. Assuming investment costs of 200,000 to 300,000€ [2], the wastewater recycling plant would have been amortized in three to four years in consideration of the reduced water costs.

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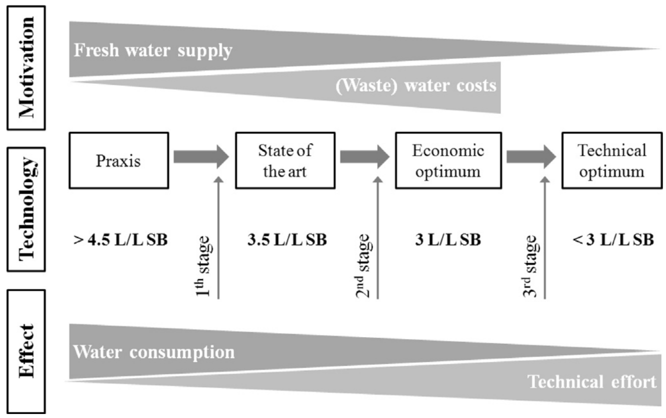

Fig. 1. Developement stages of water management in breweries [10].

Table 1
Worldwide breweries applying membrane systems for an internal water reuse.

Year	Brewery	Production site	Membrane system
2010	Bluetongue Brewery	Warnervale, Australia	MBR+RO
2009	Lion Nathan's Castlemaine Perkins	Brisbane, Australia	MF+RO
2009	SAB Tanzania Breweries	Dar es Salaam, Tanzania	MBR+RO
2008	Cerveceria Polar	Caracas, Venezuela	MBR+RO
2007	Boon Rawd Brewery	Khon Kaen, Thailand	UF+RO
2007	Martens Brewery	Bocholt, Belgium	MBR+RO+UV
2006	Konig Brewery	Duisburg, Germany	MBR+RO
2004	Foster's CUB Yatala	Yatala, Australia	MF+RO

For these reasons, the advanced treatment of biologically cleaned brewery wastewater by membrane processes to close internal water cycles and to reuse the recycled wastewater for processes without product contact was the objective of several research projects [1,2]. Former investigations related to the recycling of process water flows are focussed on the reduction of fresh water consumption for bottle washing with preferably low technical effort [6], because of the huge amounts of fresh water needed and the high potential for water reuse. Furthermore, investigations were carried out to treat the regeneration and rinsing waters from weakly acidic cation exchangers [12] as well as to recycle the polyvinylpolypyrrolidone (PVPP) regeneration lye [7].

In the last decade, some worldwide operating breweries have already applied large-scale end-of-pipe plants for wastewater recycling [4,5] (Table 1). Central components are two-staged membrane systems, which can be operated stably, but there is still potential for improvement with a positive economic impact. This is resulting from the low scientific knowledge about the effects of brewery-specific wastewater ingredients on the filtration performance of membrane processes. Furthermore, there is a broad variety in the wastewater composition within a brewery (Table 2), but also between different breweries so that membrane technology has to meet different technical demands.

During membrane filtration, several ingredients of brewery wastewater can cause blockings and cover layers (fouling, scaling). According to Cornel [13], the following substances are regarded as potential impurities: long-stranded, filamentous, highly abrasive or sharp-edged ingredients (e.g. kieselguhr), scaling-causing ingredients (e.g. calcium, phosphate, sulfate, barium, strontium and silicates), fouling-causing ingredients (e.g. persistent colloids, defoamers, and surfactants) as well as wastewater flows with high product or co-product load (e.g. high yeast concentration, out-pressed liquid from spent grain, water flows with concentrated protein, polyphenol and polysaccharide fractions from filtration processes). To keep the permeate flux on an economically acceptable level, frequent and partly extensive membrane cleaning which causes a significant chemical and energy consumption has to be conducted. Moreover, every cleaning process reduces the durability of membranes and the spent cleaning solutions have to be disposed and/or treated. Due to the complexity of the wastewater matrix (Fig. 2), it is difficult to assess which substances cause blockings on and/or within membranes and which do not decrease the filtration performance.

The innovative approach of this study was to optimize membrane systems applied for wastewater recycling in breweries in consideration of economic efficiency and safety of operation by defining and adjusting the wastewater matrix. These investigations have been carried out for the first time. In the past and present, research projects and technical applications mainly focus on the optimization of membrane systems by adjusting operating conditions and module configurations (end-of-pipe approach). In this study, a precautionary approach is pursued for a sustainable, safe and economical application of water reuse technologies. Critical wastewater ingredients and process water flows will be substituted or treated separately *before* feeding into the total wastewater stream and *before* they can have a negative effect on the filtration performance of membranes. This approach provides completely new opportunities to optimize membrane systems applied for wastewater reuse and can also be easily transferred to other sectors of industries.

Furthermore, the carried out characterization of brewery wastewater is of high interest. Comprehensive analyses date back several years [14,15], so that the wastewater composition is expected to be modified due to changes in production process, product ranges and/or wastewater treatment concepts.

2. Materials and methods

2.1. Sampling

To identify process water flows critical for membrane filtration, seven breweries with similar product ranges and different wastewater treatment plants were selected. Their annual beer output and the output distribution are shown in Fig. 3. Samples of process water flows with high organic and/or salt loads were taken for quantitative and qualitative analysis. Therefore, alkaline cleaning and regeneration waters from the sections brew house, filtration cellar, fermenting cellar and filling were sampled. The grab sampling of the breweries was conducted within the time period 02/2010 to 11/2011. The amount of samples was based upon the process-specific availability on the respective day of sampling. Table 3 gives an overview of the sampling of process water flows from the breweries A to F.

2.2. Analytical methods

The following parameters were analyzed to characterize process water flows from breweries and/or feed, permeate and concentrate samples during laboratory-scale experiments: pH, conductivity, chemical oxygen demand (COD), biological oxygen demand (BOD), total and dissolved organic carbon (TOC and DOC), total nitrogen bound (TNb), particle size, polyphenols as well as fractions of dissolved organic carbon.

Conductivity and pH were measured by using Knick Portamess 913 Cond (Berlin, Germany) and WTW microprocessor pH meter