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Novel cold sterilization and stabilization process applied to a pale lager

Alessio Cimini, Mauro Moresi *

Department for Innovation in the Biological, Agrofood and Forestry Systems, University of Tuscia, Via S.C. de Lellis, 01100 Viterbo, Italy

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ABSTRACT

In this work, the crossflow microfiltration (CFMF) performance of different lots of a rough pale lager, produced in the industrial brewery Birra Peroni Srl (Rome, Italy), was assessed in a bench-top plant, equipped with a 0.8-μm ceramic tubular membrane module, under constant crossflow velocity (6 m s^{-1}), transmembrane pressure difference (3.74 bar), temperature (10 °C), and periodic CO_2 backflushing. The average permeation flux increased from (86 ± 8) to (252 ± 21) $\text{L m}^{-2} \text{h}^{-1}$, provided that the rough beer was fed as such or pre-centrifuged to minimize the fouling contribution of yeast cells and aggregates, respectively. In both cases, the permeate turbidity at 20 °C fulfilled that recommended by the European Brewery Convention standards; but, as expected, the chill haze at 0 °C was quite higher than 0.6 EBC unit. A preliminary stabilization of pre-centrifuged beer using 0.5 g L^{-1} of regenerable polyvinylpolypyrrolidone (PVPP) at 0 °C for 24 h allowed the permeate chill haze to be reduced to (0.63 ± 0.22) EBC unit; but the average permeation flux fell to (161 ± 21) $\text{L m}^{-2} \text{h}^{-1}$. By removing the residual PVPP particles from stabilized beer using a 2.7-μm filter before CFMF, it was possible not only to re-enhance the average permeation flux up to $337 \text{ L m}^{-2} \text{h}^{-1}$ (this value being in line with those achievable with conventional DE-filters), but also to obtain a chill haze-free permeate ready for aseptically packaging.

By referring to an industrial plant capacity of 2×10^6 h L of lager beer, the estimated overall operating costs and global warming potential for this novel combined pale lager clarification and PVPP stabilization procedure reduced to about the 30% of those associated with the current industrial DE-filtration and regenerable PVPP stabilization procedures.

1. Introduction

The beer brewing process consists of a series of steps directed to convert a starchy material (e.g., malted barley including sometimes a few adjuncts, such as maize grits and wheat) into a sugar-rich liquor (i.e., the wort or extract) to be then transformed into an alcoholic liquid by yeast fermentation. These steps comprise barley malt milling, and mashing; wort lautering, boiling, whirlpooling, cooling, oxygenation, and fermentation (Eßlinger, 2009). Once it has been separated from the tank bottom deposit, the rough or green beer (RB) is filtered in the presence of filter aids (i.e., kieselguhr or diatomaceous earth, DE) to remove yeasts and suspended solids; stabilized to avoid permanent or chill haze (Siebert et al., 1996); packaged into bottles or cans, and finally pasteurized to remove all microbial contamination. In particular, haze precursors are commonly removed by using polyvinylpolypyrrolidone (PVPP), either alone or combined with selected carrageenan or silica xerogel (Rehmanji et al., 2005), or agarose beads (Taylor et al., 2006), to assure beer stability during storage.

The World Health Organization has raised concerns about the potential adverse environmental, health, and safety implications of DE handling and spent DE-sludge disposal, the crystalline silica content of such materials triggering lung disease (Fillaudeau et al., 2006). Thus, the beer industry is interested to novel DE-free crossflow microfiltration (CFMF) systems, even if the successful industrial applications currently available suffer from quite lower permeate fluxes ($50\text{–}100 \text{ L m}^{-2} \text{h}^{-1}$) than those achievable ($250\text{–}500 \text{ L m}^{-2} \text{h}^{-1}$) with conventional powder filters (Buttrick, 2007; Fillaudeau et al., 2006).

Since the early 90s (Gir and Leeder, 1992), a large number of studies have pointed out the techno-economic advantages and disadvantages of rough beer clarification using membranes by comparing not only the CFMF performance in terms of the average permeation flux, but also the quality of permeated beers thanks to the removal of beer-spoiling organisms without any thermal treatment, as well as the retention of essential beer constituents and fresher-tasting products (Ambrosi et al., 2014; Fillaudeau and Carrère, 2002; Fillaudeau et al., 2007). Also the main

* Corresponding author. Tel.: +39 0761 357497; fax: +39 0761 357498.
E-mail address: mmoresi@unitus.it (M. Moresi).

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Nomenclature

A_m	overall membrane surface area installed (m^2)
C	centrifugally pretreated rough beer
CE	centrifuge
CFMF	crossflow microfiltration
CFU	colony-forming unit
C_o	overall beer clarification and stabilization costs (€ hL^{-1})
D	storage tank for clarified and PVPP stabilized beer
DE	diatomaceous earth
EC	enzymatically and centrifugally pretreated rough beer
EE	electric energy
FT	filtrap cartridge
GHG	greenhouse gas
GWP	100-yr Global Warming Potential (kg CO_{2e} hL^{-1})
H	beer turbidity (EBC unit)
J^*	quasi steady-state permeation flux ($L\,m^{-2}\,h^{-1}$)
J_v	instantaneous volumetric permeation flux ($L\,m^{-2}\,h^{-1}$)
$J_{v,av}$	average volumetric permeation flux, as defined by Eq. (1) ($L\,m^{-2}\,h^{-1}$)
K	Kieselguhr
KS	Kieselguhr sludges
L_W	membrane constant for water transport ($L\,m^{-2}\,h^{-1}bar^{-1}$)
MM	CFMF membrane module
N_{CE}	motor power installed to drive CE (kW)
N_{PC1}	motor power installed to drive PC1 (kW)
N_{PC2}	motor power installed to drive PC2 (kW)
PC1	primary centrifugal pump
PC2	recirculation centrifugal pump
P_{CE}	input CE pressure (bar)
P_F	input MM pressure (bar)
P_P	permeate-side output pressure (bar)
P_R	retentate-side output pressure (bar)
P_{RB}	input PC1 pressure (bar)
P_{SB}	input PC2 pressure (bar)
PVPP	polyvinylpolypyrrolidone
PW	process water
Q_F	CFMF feed flow rate ($hL\,h^{-1}$)
Q_P	permeate flow rate ($hL\,h^{-1}$)
Q_R	retentate flow rate ($hL\,h^{-1}$)
Q_{RB}	rough beer flow rate ($hL\,h^{-1}$)
RB	rough beer
R-PVPP	regenerable PVPP
S	live steam
S-PVPP	single use PVPP
T	process temperature (°C)
t	process time (s or h)
t_{max}	end time of any rough beer permeation test (h)
TMP	transmembrane pressure difference (bar)
TP	total phenolic content ($mg\,L^{-1}$)
v_S	crossflow velocity ($m\,s^{-1}$)
WW	wastewaters

mechanisms of fouling formation during membrane beer clarification have been reviewed (van der Sman et al., 2012).

Generally speaking, the membrane-filtered beers fulfill the haze specification for a clear beer according to the European Brewery Convention (EBC) norms, the turbidity of 0.5 EBC unit being referred as A1-Brilliant (European Brewing Convention, 2010). However, similarly to the great majority of DE-filtered beers, the membrane-filtered beers need to be stabilized to maintain such a

Table 1
Mean and standard deviation of the total polyphenol content (TP), and turbidity (H) at (20 and 0) °C of beer samples, as such, precentrifuged, PVPP stabilized, rough filtered, and/or micro-filtered (CFMF), together with the quasi-steady state (J^*) and average ($J_{v,av}$) permeation fluxes observed in some total recycle tests carried out at $T \approx 10$ °C, TMP = 3.74 bar, $v_S = 6\ m\ s^{-1}$, and periodic CO_2 backflushing.

Rough beer samples	t (h)	TP ($mg\,L^{-1}$)	$H_{20\,°C}$ (EBC unit)	$H_{0\,°C}$ (EBC unit)	J^* ($L\,m^{-2}\,h^{-1}$)	$J_{v,av}$ ($L\,m^{-2}\,h^{-1}$)
Rough beer as such						
RB1	0	176 ± 2	12.1 ± 0.1	13.3 ± 0.2		
	CFMF	162 ± 5	0.48 ± 0.01	2.32 ± 0.07	62 ± 6	86
RB2	0	185 ± 2	15.6 ± 0.1	17.5 ± 0.2		
	CFMF	179 ± 3	0.47 ± 0.01	3.62 ± 0.07	60 ± 6	89
Pre-centrifuged beer						
RB3	0	187 ± 2	1.57 ± 0.1	2.12 ± 0.6		
	CFMF	162 ± 4	0.59 ± 0.01	1.1 ± 0.1	129 ± 12	267
RB4	0	189 ± 3	1.78 ± 0.1	2.64 ± 0.7		
	CFMF	173 ± 2	0.55 ± 0.01	1.2 ± 0.1	154 ± 10	237
Pre-centrifuged and PVPP stabilized beer						
RB5	0	165 ± 1	1.40 ± 0.03	2.67 ± 0.21		
	24	89 ± 4	1.03 ± 0.12	1.23 ± 0.19		
	CFMF	nd	0.35 ± 0.02	0.45 ± 0.03	139 ± 16	183
RB6	0	199 ± 4	1.70 ± 0.04	18.58 ± 0.79		
	24	121 ± 6	7.43 ± 0.16	10.92 ± 0.68		
	CFMF	nd	0.49 ± 0.03	0.59 ± 0.32	114 ± 12	141
RB7	0	192 ± 6	1.85 ± 0.07	16.78 ± 0.05		
	24	108 ± 8	1.41 ± 0.32	2.68 ± 0.39		
	CFMF	nd	0.43 ± 0.07	0.57 ± 0.02	100 ± 10	158
Pre-centrifuged, PVPP stabilized, and pre-filtered beer						
RB8	0	227 ± 7	1.71 ± 0.14	17.0 ± 0.4		
	24	138 ± 6	0.76 ± 0.05	0.91 ± 0.06		
	CFMF	84 ± 2	0.23 ± 0.02	0.31 ± 0.02	137 ± 9	338
RB9	0	263 ± 4	1.71 ± 0.14	32 ± 1		
	24	147 ± 6	0.77 ± 0.05	0.91 ± 0.08		
	CFMF	87 ± 1	0.22 ± 0.01	0.31 ± 0.06	139 ± 7	336

nd: not determined.