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Production and characterization of alcohol-free beer by membrane process

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ABSTRACT

Alcohol-free beer is a secondary product of brewing industry, nevertheless, its production is motivated by the global trend for healthier lifestyle and the awareness about the benefits of moderate beer drinking. A modified osmotic distillation was investigated in order to minimize the loss of volatile compounds, to reduce the water consumption and, hence, decrease the environmental impact of the process. In particular, the osmotic distillation technique here proposed consists of recycling the stripping solutions from a preliminary dealcoholization process of a batch of beer to that of further batches.

A cost estimation showed that the proposed modification of the process was able to significantly reduce the cost of stripping water, which negatively influenced the operating costs in conventional osmotic distillation processes.

Regarding to the beer quality, properties such as colour and polyphenols content were almost unchanged in the dealcoholized beer with respect to the original one while bitterness, foam stability, turbidity, O_2 and CO_2 content were statistically different.

From the comparison of alcohol-free and original beer, a modification in the content of volatile compounds was observed. The volatile compounds losses were respectively of 77% for higher alcohols, 99% for esters and 93% for aldehydes. However, the loss of volatile compounds obtained in this study was very similar to literature results on beer dealcoholization by dialysis, falling film evaporation, vacuum distillation and reverse osmosis.

Post treatments and blending techniques such as carbonation, addition of fresh yeasts following by maturation or by blending with krausen, original or aromatic beer may be used to improve the product quality.
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1. Introduction

Beer is a widely popular beverage spread throughout the world with different alcoholic strength, usually ranging from 3 to 6 vol.% (Bamforth, 2004). Recently, there has been an increased market share for low-alcohol (<1.2 vol.%) and alcohol-free (<0.5 vol.%) beers, although they still represent secondary segment of the brewing market. The maximum alcohol content for marketing of beer at reduced alcohol content is different in various countries. Unlike of UK where alcohol-free beers must not exceed 0.05 vol.% (Brányik et al., 2012), in the European countries the alcohol-free beer is characterized by an alcohol content lower than 0.5 vol.%, whereas a low-alcohol beer has an alcoholic residue less than 1.2 vol.% (Porretta and

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Nomenclature

A	membrane area (m^2)
C	concentration (vol.%)
d	diameter (m)
D	diffusion coefficient (m^2/s)
H	partition coefficient (Pa m^3/mol)
k	mass transfer coefficient (m/s)
K	mass transfer coefficient g/(m^2 s Pa)
M	molecular weight (kg/kmol)
Q	flow rate (m^3/s)
R	ideal gas constant (J/K mol)
Re	Reynolds number
Sc	Schmidt number
Sh	Sherwood number
t	time (s)
V	volume (L)

Greek letters

α	constant
β	constant
δ	membrane thickness (m)
ε	membrane porosity
μ	fluid viscosity (Pa s)
ρ	fluid density (kg/m^3)
τ	membrane tortuosity
ϕ	packing density

Subscripts

e	effective
exp	experimental
f	feed
h	hydraulic
in	membrane inlet
k	Knudsen
lm	logarithmic mean
m	membrane
m-air	molecular-air
out	membrane inlet
ov	overall
p	pore
s	stripping

Superscripts

EtOH	ethanol

Donadini, 2008). Moreover in the United States, alcohol-free beer means that there is no alcohol present while the upper limit of 0.5 vol.% corresponds to so-called non-alcoholic beer (Montanari et al., 2009).

The increasing worldwide production of alcohol-free beer reflects the global trend for healthier lifestyle (Lehnert et al., 2009) and the awareness about the benefits of moderate beer drinking (Brányik et al., 2012). In the European Union, the largest consumers of beer with low alcohol content are the Spanish according to Euromonitor International (http://www.euromonitor.com) which attests sales of 5.8 L per person, followed by the Muslim population, which have cultural prohibitions against alcohol consumption (Brat, 2011).

Moreover, low alcohol beer is a good source of nutrients such as vitamins, minerals, soluble fibres and antioxidants (e.g. polyphenols, flavonoids) (Brányik et al., 2012; Zhao et al., 2010), motivating the production of such drink.

Many processes have been used to produce low-alcohol or alcohol-free beer: physical processes such as dialysis (Bandel et al., 1986; Zufall and Wackerbauer, 2000b), reverse osmosis (Stein, 1993; Kavanagh et al., 1991), vacuum rectification and evaporation (Narziss et al., 1993) and biological processes such as controlled (suppressed) alcohol formation (Lehnert et al., 2009), use of special yeasts (Narziss et al., 1992) and cold contact process (Montanari et al., 2009). All of the above methods influence the taste and flavour of the beer.

In particular, beers produced by means of arrested fermentation are usually criticized for different defects such as: lack of fruity aroma, strong worty flavour, sometimes obtrusive and papery (Narziss et al., 1992). Several carbonyl compounds (i.e. 3-methylthiopropionaldehyde) are found to contribute to the worty off-flavour, which is the most common defect of alcohol-free beers produced by biological methods (Perpete and Collin, 1999). Thermal methods, such as vacuum rectification and evaporation determine lower colloidal stability, cause light caramel flavour and high volatile compounds losses; whereas, reverse osmosis causes less body and low aromatic profile of beer.

Among membrane processes, the osmotic distillation, also called isothermal membrane distillation (Hogan et al., 1998) and evaporative pertraction (Michaels et al., 1998; Diban et al., 2008), has been recently used to remove alcohol from alcoholic beverages, e.g. wine, (Liguori et al., 2010, 2013a,b; Varavuth et al., 2009; Diban et al., 2008) and more recently from beer (Russo et al., 2013). The main advantage of this technology is the low operating temperature and pressure, limiting the thermal damage to components, such as aroma and flavour losses (Diban et al., 2008).

In a previous work (Russo et al., 2013), alcohol-free beer (alcohol content ≤0.5 vol.%) was produced from a commercial lager beer by osmotic distillation technique. The effect of different stripping agents (pure water and permeate solutions) for ethanol removal on some chemical and physical properties of the dealcoholized beer (i.e. alcohol content, colour, pH, polyphenols, antioxidant activity) was investigated. The parameters investigated do not significantly differ between the two dealcoholized beers (obtained by different stripping agents) and original beer.

The acceptability of the beer is strongly influenced by other properties of the beer such as: bitterness, turbidity, foam stability, O_2 and CO_2 content and mainly by the presence of volatile compounds produced during the brewing process, which affect drink aroma and flavour. Hence, the knowledge about the change of these properties during beer dealcoholization results of primary importance.

The aim of this paper is to study the feasibility of applying the osmotic distillation for beer dealcoholization using as stripping agents permeate solutions recycled by a preliminary dealcoholization process. This choice of stripping agent is considered a valid alternative in order to minimize the loss of volatile compounds, to reduce the water consumption and to decrease the environmental impact of the process, even though a slightly longer process time is required. Moreover, ethanol recovery from the stripping solutions can be further used as a potential blending stock in the manufacture of alcoholic beverages. The main beer properties (i.e. gravity, bitterness, turbidity, foam stability, O_2 and CO_2 content, alcohol content, colour, pH, polyphenols, antioxidant activity) as well

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