STUDYING BEER DEALCOHOLIZATION BY REVERSE OSMOSIS

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Abstract
The production of low-alcohol beer (LAB) or alcohol-free beer (AFB) is important because of several reasons. In this research, pale lager beer samples were dealcoholized by reverse osmosis (RO) at a temperature of 15 ± 1 °C. Alfa Laval RO99 membrane with 0.05 m^2 active surface was used for dealcoholization processes. Flux values were measured during the separations. Dynamic viscosity values and ethanol content of beer and permeate samples were measured. Initial flux values were determined by linear regression. Initial ethanol flux ($J_{EtOH\ 0}$) values were calculated from initial flux values and ethanol content values. 2^P type full factorial experimental design was applied, the two factors were the following: Transmembrane Pressure (TMP): 10, 20, 30 bar and Retentate Flow Rate (Q): 120, 180, 240 L hr^{-1}. $J_{EtOH\ 0}$ was considered as a response of the full factorial experimental design. The effect sizes of the significant parameters were calculated. The global maximum of the objective function was found with self-developed Grid Search code. The best fitted linear function was as follows:
$J_{EtOH\ 0} = 80.871 + 41.094 \times x_{TMP}$
The effect size of the significant parameter was the following: TMP: 1.20. The optimal value of the factor amounted to TMP = 30 bar. The predicted $J_{EtOH\ 0}$ under the above condition was 121.965 g m^{-2} hr^{-1}. The detailed method in this study can be implemented by breweries.

Introduction
The scope of this research is to study beer dealcoholization (BDA) by reverse osmosis (RO).
There can be several reasons for low-alcohol beer (LAB) or alcohol-free beer (AFB) production. The reasons are the following: increase in the overall production by introduce new products in countries with highly competative markets; provide beer consumers with products prior or during their activites (driving motor vehicles, operating machinery, doing sports) or under conditions (pregnancy, medication) irreconcilable with alcohol consumption; penetrate beverage markets in countries, where alcohol consumption is forbidden for religious reasons [1]. There are different methods for LAB or AFB production. One of the groups of the methods are the membrane separation processes. Membrane separation processes provide promising alternatives for separating the alcohol after the fermentation process and include such advantages as lower energy consumption, no chemical additives, and operation at mild temperatures, therefore reducing the impact of heat on the product [2]. In this research, a membrane separation process for BDA is investigated, namely RO. The most important

parameters of the BDA by RO are the permeate flux and the ethanol concentration in the permeate. These parameters can be combined into one parameter: ethanol flux [3].
The goals of this research are to determine the analytical parameters of beer and permeate samples (ethanol content values for the physical modelling); to determine the hydrodynamic parameters of the membrane separations for the (physical modelling); to calculate the ethanol flux values of the membrane separations for the response (physical modelling) of the experimental design; to analyse the experimental design (mathematical modelling) of the membrane separations (parameter and effect size estimation); to optimize the objective function (the mathematical model) extracted from the analysis of the experimental design.

Experimental

Beers

0.5 L canned Soproni Klasszikus pale lager beers (HEINEKEN Hungária, Hungary) with 4.5% (V/V) ethanol content were used during beer dealcoholization by reverse osmosis.

Membrane

RO99 flat sheet polyester membrane (Alfa Laval, Sweden) with 0.05 m^2 active surface was used for dealcoholization processes.

Membrane separation process

Dealcoholization experiments were performed according to the experimental design at a temperature of 15 ± 1 °C. Flux values were measured during the separations.

Analytical parameters

Dynamic viscosity values of beer and permeate samples were measured with Physica MCR 51 Rheometer (Anton-Paar Hungary, Hungary) with DG27 double gap concentric cylinder measurement system. Ethanol content values of beer and permeate samples were measured with Alcolyzer Plus (Anton-Paar, Austria).

Linear regression

Based on a linear model, initial flux values were determined by regression in IBM SPSS Statistics 25 software (IBM, USA).

Hydrodynamic parameters

Initial ethanol flux values were calculated from initial flux values and ethanol content values.

Modelling

2^P type full factorial experimental design was applied, the two factors were the following: Transmembrane Pressure (TMP): 10, 20, 30 bar and Retentate Flow Rate (Q): 120, 180, 240 L hr^{-1}. Initial ethanol flux ($J_{EtOH\,0}$) was considered as a response of the full factorial experimental design. Factors were coded to standard values (x): –1, 0, 1. The results of the experimental design were analyzed in R 3.5.1 software (R Foundation for Statistical Computing, Austria) using RcmdrPlugin.DoE package (R Foundation for Statistical Computing, Austria) and RStudio 1.2.1335 software (RStudio, USA). The non-significant parameters were eliminated. The effect size of the significant parameter was calculated. Normality of residuals was accepted by Shapiro-Wilk normality test ($p = 0.72$). The global maximum of the objective function was found with self-developed Grid Search code in Scilab 6.1.0 software (ESI Group, France).

Results and discussion

The best fitted linear function that describes the relation between factors and response was as follows:

$J_{EtOH\ 0} = 80.871 + 41.094 \times x_{TMP}$

The non-significant parameters (Q and interaction) were eliminated. Model accuracy and determination coefficients of the objective function were also significant ($F(1;5) = 143.1$; $p < 0.001$; Multiple $R^2 = 0.97$; Adjusted $R^2 = 0.96$). The effect size of the significant parameter was the following: TMP: 1.20. The optimal value of the factor amounted to TMP = 30 bar. The predicted $J_{EtOH\ 0}$ under the above condition was 121.965 g m^{-2} hr^{-1}.

Conclusion

According to the analysis of the experimental design, TMP had significant effect, while Q had no significant effect on $J_{EtOH\ 0}$ with the given parameters. Furthermore, there was no significant interaction between the factors. This means that the commercial breweries should only focus on the optimization of TMP. BDA by RO can be performed with lowest required Q, which results in lower energy consumption. The lower energy consumption is important because of environmental and economic issues. Furthermore, TMP had interactive effect on $J_{EtOH\ 0}$. Based on the results of the optimization, the highest $J_{EtOH\ 0}$ could be achieved with the highest TMP. Thus, commercial breweries should set the TMP at this level. In a later exercise, beers with different alcohol and extract content could be dealcoholized by RO.

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