***“Investigation of multicomponent adsorption behaviour of aldehydes in malt-based beverages for selective removal of wort-flavour by sequential statistical experimental design”***

**Introduction**

Current trends in the beverage industry show a consumers shift towards more health-conscious products. Therefore, there is an interest to create healthier, alcohol-free options for the consumers, which preserve the high quality of the original beverage. A sensory imbalance often observed in alcohol-free beers is the over-perception of wort flavours [1]. In general it is recognised that these off-flavours are caused by so-called Strecker aldehydes, which are formed by a heat-induced reaction between a reducing sugar and an amino acid [2]. Moreover, their formation may also be caused by other reactive carbonyls such as lipid derived carbonyls or quinones from polyphenol oxidation [3-6]. As a result of the complexity of involved reaction pathways it is difficult to prevent Strecker-aldehyde formation [7, 8]. Therefore, new process designs are required to be able to engineer the desired flavour profile and fine-tune the aroma concentration to the respective product.

In brewing literature, studies have been done on reducing Strecker aldehydes in alcohol-free beer by a restricted or continuous fermentation (biological removal) [9-11] or by addition of certain beer constituents such as amino acids, wort proteins or polyphenols that bind the aldehydes [11, 12]. Drawbacks of these approaches are that the concentration of the target compounds are not sufficiently reduced and that ethanol is often a side product. Newer developments include membrane-based separation of flavours [13, 14], but selectivity is yet insufficient. Other approaches such as extraction, adsorptive or reactive removal have been restricted to the application in organic chemistry, food packaging or bulk chemical production [15-22].

Currently, there are no downstream unit operations available to selectively remove wort flavours without impacting the overall taste and nutritional quality of the product. The process requires a technology, which combines a high selectivity at mild operation conditions with low capital investment and operational cost. A suitable choice for this challenging task was identified to be adsorption [23, 24]. The goal of this article is to investigate a selective adsorption step by screening suitable adsorbents and identify a separation medium, which is able to facilitate the specific removal under mild conditions.

Therefore, batch uptake experiments with 16 adsorbents were performed in a hopped wort base to screen for the most promising separation medium. The selection for further process development was made based on a Pugh evaluation matrix. Subsequently, multicomponent isotherm data was determined by a mixture-amount design, and a suitable model to describe the thermodynamic data was applied. A factorial experimental design was then used to study the impact of the product constituents on the model parameters to identify potential bottlenecks and propose process concepts circumventing these.

**References**

1. Brányik, T., et al., *A review of methods of low alcohol and alcohol-free beer production.* Journal of Food Engineering, 2012. **108**(4): p. 493-506.

2. Schonberg, A. and R. Moubacher, *The Strecker Degradation of -Amino Acids.* Chemical Reviews, 1952. **50**(2): p. 261-277.

3. Rizzi, G.P., *The Strecker Degradation of Amino Acids: Newer Avenues for Flavor Formation.* Food Reviews International, 2008. **24**(4): p. 416-435.

4. Hidalgo, F.J., R.M. Delgado, and R. Zamora, *Intermediate role of α-keto acids in the formation of Strecker aldehydes.* Food Chemistry, 2013. **141**(2): p. 1140-1146.

5. Hidalgo, F.J. and R. Zamora, *Strecker-type Degradation Produced by the Lipid Oxidation Products 4,5-Epoxy-2-Alkenals.* Journal of Agricultural and Food Chemistry, 2004. **52**(23): p. 7126-7131.

6. Delgado, R.M., R. Zamora, and F.J. Hidalgo, *Contribution of Phenolic Compounds to Food Flavors: Strecker-Type Degradation of Amines and Amino Acids Produced by o- and p-Diphenols.* Journal of Agricultural and Food Chemistry, 2015. **63**(1): p. 312-318.

7. Saison, D., et al., *Contribution of staling compounds to the aged flavour of lager beer by studying their flavour thresholds.* Food Chemistry, 2009. **114**(4): p. 1206-1215.

8. Baert, J.J., et al., *On the origin of free and bound staling aldehydes in beer.* J Agric Food Chem, 2012. **60**(46): p. 11449-72.

9. Van Iersel, M.F.M., et al., *Influence of yeast immobilization on fermentation and aldehyde reduction during the production of alcohol-free beer.* Enzyme and Microbial Technology, 2000. **26**(8): p. 602-607.

10. Lehnert, R., et al., *Effect of oxygen supply on flavor formation during continuous alcohol-free beer production: A model study.* Journal of the American Society of Brewing Chemists, 2008. **66**(4): p. 233-238.

11. Perpète, P. and S. Collin, *Fate of the worty flavours in a cold contact fermentation.* Food Chemistry, 1999. **66**(3): p. 359-363.

12. Perpète, P. and S. Collin, *How to improve the enzymatic worty flavour reduction in a cold contact fermentation.* Food Chemistry, 2000. **70**(4): p. 457-462.

13. Catarino, M., A. Ferreira, and A. Mendes, *Study and optimization of aroma recovery from beer by pervaporation.* Journal of Membrane Science, 2009. **341**(1-2): p. 51-59.

14. Catarino, M. and A. Mendes, *Non-alcoholic beer - A new industrial process.* Separation and Purification Technology, 2011. **79**(3): p. 342-351.

15. Drese, J.H., A.D. Talley, and C.W. Jones, *Aminosilica Materials as Adsorbents for the Selective Removal of Aldehydes and Ketones from Simulated Bio-Oil.* ChemSusChem, 2011. **4**(3): p. 379-385.

16. Jeřábek, K., L. Hanková, and Z. Prokop, *Post-crosslinked polymer adsorbents and their properties for separation of furfural from aqueous solutions.* Reactive Polymers, 1994. **23**(2): p. 107-112.

17. Lucas, S., et al., *Adsorption isotherms for ethylacetate and furfural on activated carbon from supercritical carbon dioxide.* Fluid Phase Equilibria, 2004. **219**(2): p. 171-179.

18. Nomura, A. and C.W. Jones, *Amine-Functionalized Porous Silicas as Adsorbents for Aldehyde Abatement.* ACS Applied Materials & Interfaces, 2013. **5**(12): p. 5569-5577.

19. Gesser, H.D. and S. Fu, *Removal of aldehydes and acidic pollutants from indoor air.* Environmental Science & Technology, 1990. **24**(4): p. 495-497.

20. Suloff, E.C., *Sorption behaviour of an aliphatic series of aldehydes in the presence of poly(ethylene terephthalate) blends containing aldehyde scavenging agents*. 2002, Virginia Polytech Institute and State University: Blacksburg, Virginia.

21. DelNobile, M.A., et al., *Modeling of Hexanal Sorption Kinetic in an Aldehydes Scavenger Film Intended for Food Packaging Applications.* Journal of Food Science, 2002. **67**(7): p. 2687-2691.

22. Saadati, F., et al., *Preparation and characterization of nanosized copper (II) oxide embedded in hyper-cross-linked polystyrene: Highly efficient catalyst for aqueous-phase oxidation of aldehydes to carboxylic acids.* Catalysis Communications, 2016. **79**: p. 26-30.

23. Saffarionpour, S., et al., *Selective adsorption of flavor-active components on hydrophobic resins.* Journal of Chromatography A, 2016. **1476**: p. 25-34.

24. Ottens, M., S. Saffarionpour, and T.R. Noordman, *Method of producing beer having a tailored flavour profile (EP14183788.0)*, in *Patentscope*. 2016, Heineken Supply Chain B.V.