0. Title

Enhancing Main Fermentation Velocities in Beer by the Use of a Membrane Bioreactor – Approach and First Results

1. Abstract

The potential of most recent membrane technology is still unaccounted for in many respects. Combining fermentation with up-to-date membrane technology forming a membrane bioreactor allows the adjustment of the cell count on a high level, resulting in an increase in space time yield. Applied on the manufacturing of beer, main fermentation times of below 24 h seem possible, avoiding disadvantages of already known accelerated fermentation processes operated on a continuous basis. Nevertheless maintaining a sufficient membrane flux over time still poses a major problem. Different approaches were tested and module design was changed, leading to improvements. But still further investigation is necessary.

Keyword: membrane bioreactor, beer, fermentation, space time yield, fermentations velocity, module desing

2. Introduction

After producing the beer wort in the brewhouse main and second fermentation of the beer takes place in the so called cold block. As the cold block is considerably huge high investment costs are required. Hence any shortening in fermentation time leads to proportional downsizing of the fermentation volume and hence to smaller investments, but also cooling capacities and therefore operation costs.

Until now in the brewing industry state of the art is batchwise fermentation. Numerous attempts were made to shorten fermentation times, leading to up-to-date big size tank technology. As a consequence the overall production time was cut down from 20 to 31 days (6 to 10 days for main fermentation and 14 to 21 days for second fermentation) to nowadays 12 to 19 days (7 to 12 days combined main and second fermentation and 5 to 7 days cold storage before filtration). Main fermentation takes place within 3 to 4 days.

Further improvements were figured out by testing continuously operated fermentations (e.g. van de Winkel u.a. 1993, Fitzner 1998, Ludwig 2003). In these tests wort from the brewhouse passed a fermenter equipped with immobilised yeast. An overview is given by Branyik (2008). Times for the main fermentation are depending on the type of reactor and reach from 19 h to 55 h (Ludwig 2003).

Nevertheless sensory properties are different from beers fermented batchwise and hence do not fully meet consumer's expectations.

Besides ethanol as the major component derived from fermentation higher alcohols as well as esters are formed. These contribute significantly to the aroma of the final product. Furthermore pH is lowered by power 1 during main fermentation, which results from the yeast setting free organic acids and which is beneficial for the beer quality e.g. in respect to better bitter taste and improvement of the non biological stability of the beer. These and other changes are directly related to the yeast growth during the first phases of the main fermentation process as they result from the anabolic metabolism. Hence Ludwig (2003) pointed out the relevance of a well-dosed aeration and therefore a controlled yeast growth during continuously operated beer fermentation processes. In his extensive research he was able to significantly improve process stability of a continuous fermentation with immobilised yeast by applying a small but pH-controlled aeration scheme. Nevertheless long-term stability was still an issue, which presumably is caused by a non-defined yeast age and cell count in immobilised yeast fermenters.

Combining a fermenter with a membrane filtration it is possible to hold back biomass independent from any carrier material in continuous operation. Therefore the concentration of the yeast can be adjusted independently from the throughput. Corresponding approaches are well known from aerobic waste water treatment with so called membrane bioreactors (MBR).

The resulting main questions for the present project can be summarized as follows:

- Is it possible to increase main fermentation velocity from currently 3 to 4 days to < 19 h, better 10 – 12 h in a continuously operated, membrane based system by increasing the yeast cell count?
- Is it possible to achieve a beer quality comparable to beers from batchwise fermentations in order to meet consumer's expectations?
- What means are necessary to achieve high flux of the membranes on a permanent base in order to make the process economically attractive?

3. Materials and Methods

Beer wort was obtained from a commercial brewery in Hesse (Germany), commonly used for Pils or Export beer type. Trials were done in a stirred tank reactor with a maximum size of max. 8 litres, but usually filled with 5 l only. Depending on the trials the reactor was equipped with different types of modules as shown exemplarily in figure 1.

Figure 1: STR equipped with membrane modules

Two bottom fermenting yeast strains were chosen and obtained from the strain collection from Versuchs- und Lehranstalt für Brauerei e.V. in Berlin. After initial tests with well flocculating strain RH a second low flocculating yeast strain SMA-S was used for the majority of tests. The yeasts were stored under cryogenic conditions at -70°C and propagated on demand using several propagation steps in order to increase the amount of yeast to inoculate the fermenter.

The capillaries used for the modules had microfiltration size and were made out of polyethersulfone. They were characterized inhouse by Sartocheck membrane test device using forward flow test and bubble point test.

At the beginning of the membrane trials an alternating operation procedure was chosen in which green beer was taken from the reactor through the membranes, followed by a period during which wort was transferred into the reactor the opposite way again through the membranes. The idea behind this procedure was to keep the membrane free in each direction. Figure 2 demonstrates the procedure, consisting of alternating phases of green beer transfer from and wort transfer into the reactor in smalle amounts in order to minimise membrane fouling.

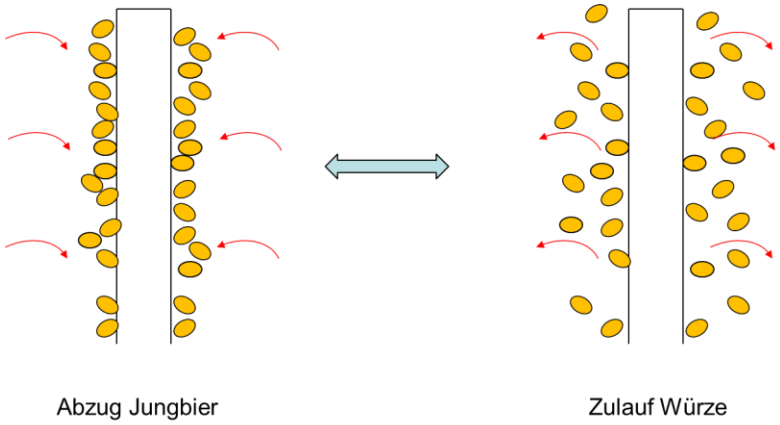

Figure 2: Alternating operation of the membranes

4. Results and Discussion

In a first set of trials yeast cell count was increased and fermentations were done batchwise in order to evaluate the impact on fermentation velocity. Compared to typical yeast cell concentrations during common main fermentation in beer of approx. 60 * 10^6 cells/ml the number of yeast cells was increased quite significantly up to 300 * 10^6 cells/ml. The results are shown in figure 3.

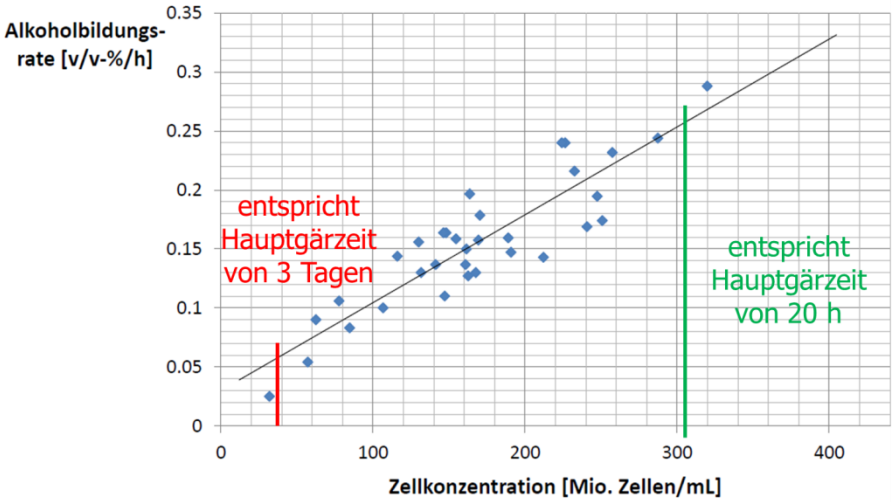

Figure 3: Fermentation velocity depending on yeast cell coun (batchwise fermentation)

At a yeast cell count of > 300 * 10^6 cells/ml main fermentation time of < 20h is possible.

Transferring the results to a continuous operation using membranes, a similar fermentation speed can be achieved (results not shown). The corresponding green beer quality concerning esters and higher alcohols are comparable to typical values for green beers produced batchwise (see table 1).

Table 1: Analytical data green beer continuous operation

	Analyse (mg/l)	Vergleichswerte (Krüger u. Anger 1990) (mg/l)
Acetaldehyd	33	N: 2 – 10 / Jungbier > 30
Ethylacetat	16	N: 10 – 40 / G: 4 – 87
1-Propanol	33	N: 7 – 16 / G: 3 – 48
Isobutanol	31	N: 5 – 20 / G: 1,5 – 84
Isoamylacetat	< 0,3	S: 1 – 2
2-Methyl-1-Butanol	28	N: 8 – 30 / G: 7 – 41
3-Methyl-1-Butanol	70	N: 30 – 70 / G: 44 – 123
2-Phenylethanol	33	N: 8 – 35 / G: 0,1 – 102
2-Phenylethylacetat	< 0,3	N: < 1

N = normal values, G = limit values

Sensory evaluation did not show any abnormalities. But it has to be pointed that this is only a snap-shot. As blocking of the membranes proves to be a major problem preventing an operation over a longer period of time, no conclusions regarding the long-term stability of the process are possible. Hence it was necessary to focus more on the module design in order to find ways of preventing the membranes from major fouling.

The module design was changed several times in order to improve backwash efficiency. Different stages of development are shown in figure 4.

Figure 4: Different stages of module design

Main focus was put on an equal distribution of the flux over the capillary surface, which was shown in trials using ink (see figure 5). Furthermore the distance between the capillaries was increased in order to ease backwashing and to avoid and minimize backmixing in dead zones of the modules

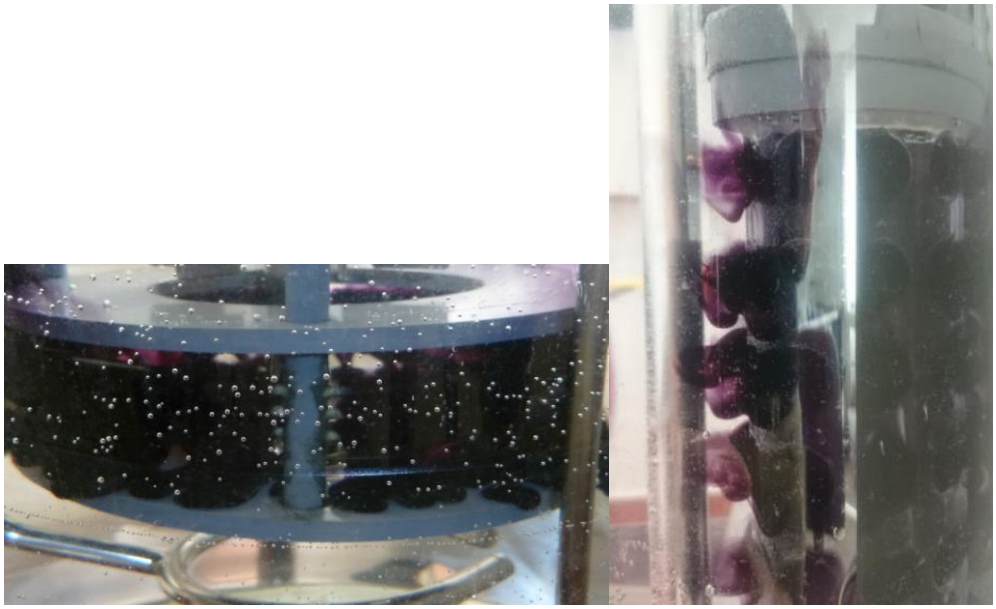

Figure 5: Flux over membrane surface using ink

Wort from the brewhouse still contains a number of particles which is referred to as cold break, consisting mainly out of proteins. Smaller particles of below 1 µm interfere with the pore size diameter, which in average was determined by the bubble point test to be 0.24 µm. Unfortunately the amount of particles within this size is significant, as can be seen in figure 6.

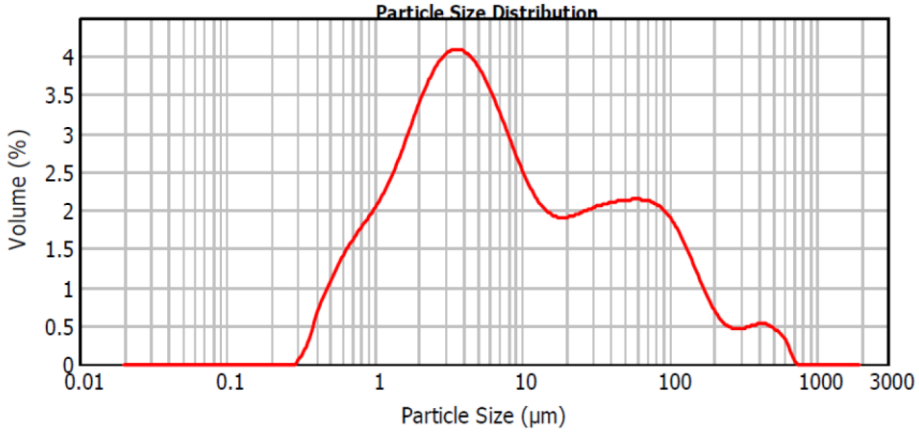

Figure 6: Particle size distribution of wort

Hence it seems to be a better choice not to transfer the wort via the membrane into the fermenter. As a consequence a different backwash procedure including filtered green beer has to be set up. Trials are going on.

5. Outlook

The fouling problem has to be resolved first before in systematic trials the impact on the long-term stability of main fermentation can be investigated further. Improvements have been made in this respect and the prospects of finally achieving a stable and technologically sound process are good, allowing major cost cuts in the brewing industry.

6. Acknowledgement

Many thanks to Rainer Schmitt and Sebastian Kaiser, who were working on the module design during their referring master thesis.

7. Literature

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