Study of spent grains sparging in brewing and distilling industry.

F.Harmegnies, R.Tigel

Meura Technologies, Voie Minckelers 1, 1348 Louvain-La-Neuve , BELGIUM

ABSTRACT

During mash filtration operation, collection of the first wort is followed by a sparging step with hot water to recover as much extract as possible from spent grain. Sparging is the longest step in the mash filtration total cycle, whatever the technology of filtration. Ideally, the volume of sparging water should be equal to the porous volume in the filtering cake ; so the sparging rate is 1.

In practice, this volume is higher due to phenomena which reduce sparging efficiency.

Also, some unwanted substances like polyphenols and aldehydes can be excessively washed out with extract recovery, most of all in last runnings.

Our presentation will describe and quantify these various phenomena through the theory of sparging and through results of trials on a pilot membrane-assisted thinbed filter. During these pilot tests, sparging efficiencies and wort composition are compared under different applied sparging conditions.

Some suggestions will be proposed to improve the sparging efficiency / time while reducing negative effects of elution in last runnings.

INTRODUCTION

In brewing and distilling industries, wort filtration is performed as well with lauter tuns as with mash filters. These technologies involve very different filtering cakes that have to be studied separately. Anyway, whatever the equipment, a relationship between cake particles size and cake thickness must be respected for correct filtration and sparging. Grist, cake thickness and efficiency are closely linked. In both systems, the sparging step is considered as a critical part of the filtration cycle due to the following reasons:

- it takes time (40 to 60% of the total operation time)
- it is linked to the yield since the target is extract recovery
- it can negatively acts on wort quality (elution of unwanted substances with last runnings)

Regarding current requirements on cycles rates, yield and wort quality, sparging is a step in the brewing process that has to be considered for optimisation.

Our work exclusively deals with sparging in thinbed membrane filters.

THEORY OF SPARGING

There is no dimensionless number characterizing sparging efficiency. Sparging trends allow the visualization of sparging efficiency as well as characterization of sparging kinetic.

Kinetic of sparging curves usually shows 2 separate phenomena during sparging : firstly a predominant displacement of dense worts by sparging liquors through the macroporosity of the filtering cake, and secondly a progressive diffusion of sugars from the microporosity, which is time dependant.

The first step is commonly expressed according to the axial dispersion model with following simplified equations:

$$\frac{y}{y0} = 0.5 + 0.5 erf\left[\phi \frac{1-R}{2\sqrt{R}}\right]$$

with: $\phi = (u_o . L / D')^{0.5}$

$R = V / S.L.\varepsilon$

y : instantaneous concentration of the filtered liquid (°Plato)

y_0: concentration of first wort (°Plato)

ϕ: coefficient of axial dispersion

R: sparging rate (volume of sparging liquor reported to the volume of impregnation liquid)

L: cake thickness (m)

u_o : percolation speed (m/sec)

D’: coefficient of axial diffusion (m^2/sec)

V: volume of sparging liquor (m^3)

S: filtering cake area (m^2)

ε : cake porosity (-)

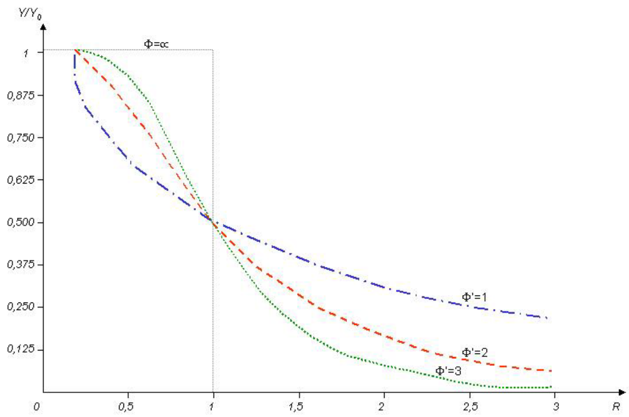

Fig. 1:sparging curves according to the model of axial dispersion

In practice, results move away from the plugflow system due to various phenomena which reduce the sparging efficiency: dilution, heterogeneity of the sparging front, diffusion,..
The higher the ϕ , the higher the sparging efficiency . A way to raise the factor ϕ is notably to decrease the size of the particles in the filtering cake. In thinbed membrane filter, this effect is obtained with the precompression step previous to sparging (reduction of cake porosity).
Moreover, our recent works have highlighted the limited influence of molecular diffusion (3). We showed similar evolutions of ions K^+ and maltose throughout the sparging step despite of significantly different coefficients of diffusion.
Also, Yasui (5) demonstrated at the WBC 2000 that extraction of nonenal potential depends on time and not on wort density.
Practical experience has then here shown that sparging time can be reduced by raising the sparging flowrate, even with a positive influence on wort quality. If however sparging flowrate can not be increased because of a too high pressure, a solution will be to stop sparging earlier. In this case, the corresponding loss of extract must be evaluated. Considering this last option, our trials also focused on last runnings composition.

MATERIAL AND METHODS
Wort was produced at pilot scale according to the following procedure:

- 84 kg Pilsner malt (spring , 2 raw)
- fine milling under water (Hydromill), mashing-in ratio of 2.3 l/kg
- pH adjusted at 5.4 with phosphoric acid
- brewing diagram: 30 min at 45°C, 20 min at 63°C, 20 min at 72°C, iodine test
- filtration at 78°C using a Meura 2001 pilot filter (filtering area of 2.8 m²) , 4 chambers of 800x800 mm

All trials were performed with similar filtration parameters, the only variable being sparging conditions.

Fig. 2 : pilot thinbed membrane filter

RESULTS AND DISCUSSION

Pilot trials were firstly carried out to continue and to confirm our previous study on sparging parameters. Figure 3 shows that there is no difference in sparging trends between a "standard" sparging (78°C, non-modified pH, low flowrate) and a modified sparging (95°C, sparging liquor at pH 4, fast flowrate). Regarding wort quality, acidification of the sparging liquor highly reduces extraction of polyphenols: 169 ppm polyphenols in weak wort at 8°P for sparging liquor at pH 4.5 compared to 293 ppm for sparging liquor at pH 7. (3)

The possibility of using sparging liquor at a temperature higher than 78°C also allows us to consider a simplification of equipments thanks to the direct use of the recollected hot water from the wort cooling system.

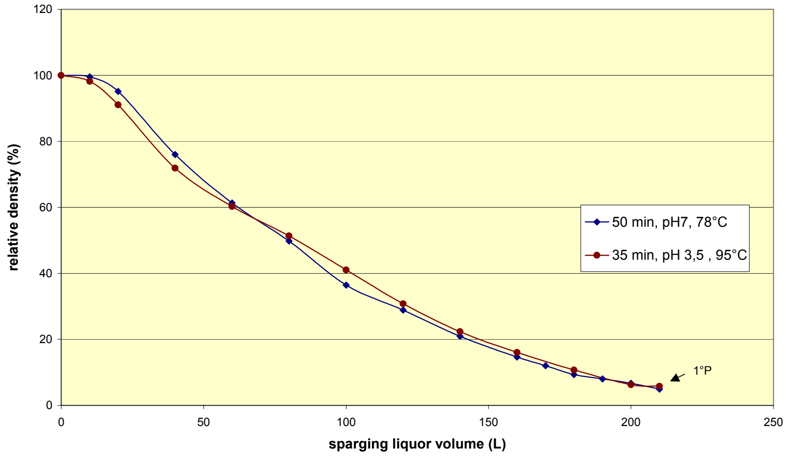

Fig.3 Influence of sparging parameters on sparging efficiency

Pilot tests were performed with prolonged sparging step to observe extraction of different compounds along the total sparging cycle , and more particularly at the end of sparging.

Trials allow to emphasize two distinct phenomena: on the one hand that sugars extraction is linked to sparging liquor volume flowing in the cake porosity, on the other hand that a "permanent extraction" of various compounds depends on operating sparging parameters (time, pH,..).

Effectively, all trials with extended sparging ended at density 0.3 – 0.4°P. Wort analyses showed that this background density was not linked to fermentable sugars.

Then the real sparging curve should consider the measured density minus the "background" density.

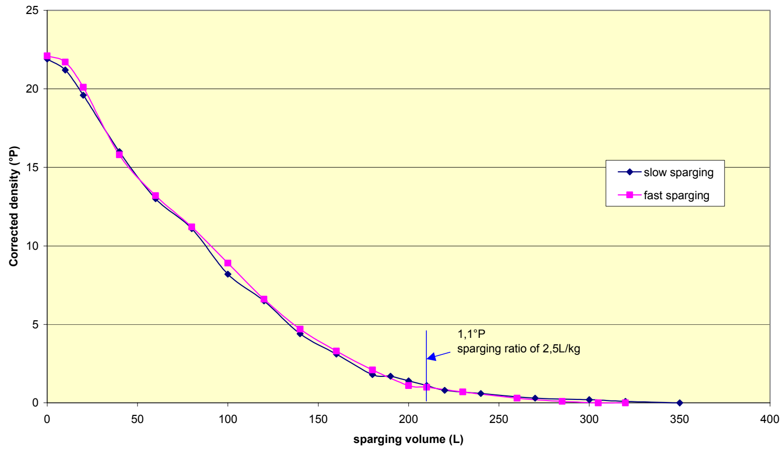

Fig 4: Sparging trends with correction of "background"density

Figure 4 illustrates "corrected" sparging trends for fast and slow sparging. As previously shown, increasing the sparging flowrate does not influence extract recovery.
In figure 5, sugars concentrations are compared between first wort, mid-sparging, end of sparging and extended sparging. When figures (with correction of background density) are reported as percentages and compared to the sugars profile in first wort, it is interesting to observe that concentrations of the different sugars decrease according to the dilution effect, even in wort at the very end of sparging

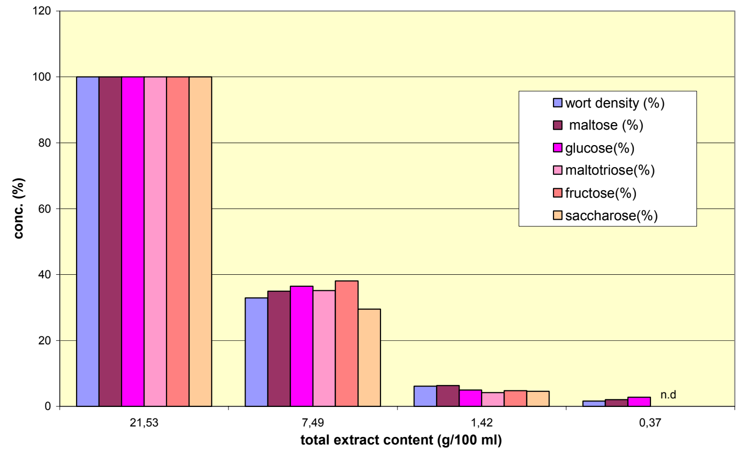

Fig. 5: Evolution of sugars concentrations during sparging

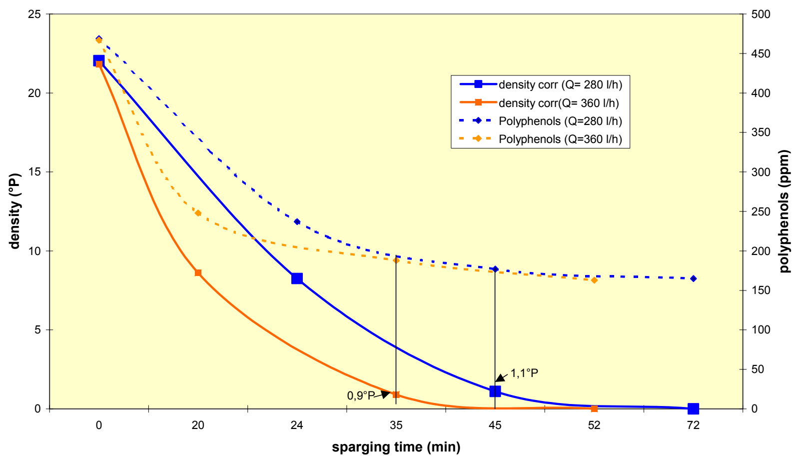

Fig.6: Influence of sparging flowrate on sugars and polyphenols extraction

Figure 6 highlights density and polyphenols extraction as a function of time, for fast and slow sparging. Whatever the sparging flowrate, the end of sparging (1 – 1.5 °P) is reached with a sparging liquor ratio of 2.5 L/kg. The permanent polyphenols value is well visualized. A similar observation was also done for soluble nitrogen. The faster the sparging is achieved, the fewer polyphenols and others substances are extracted.
By reducing the sparging time from 45 min to 35 min, the gain for wort quality is quantified by the integration of (polyphenols concentration x sparging flowrate) in the saved time.
In this case, the permanent polyphenols value is 150 ppm (sparging liquor at 95°C and pH=3.5). Of course, this figure is influenced by "quality" of sparging liquor. Acidified sparging liquor and / or gallotannins addition strongly reduce polyphenols extraction and positively contribute to beer flavour stability (1).

CONCLUSION

Our study of the influence of the sparging parameters in thinbed membrane filters (fine grist) allows us to emphasize two distinct aspects :

- The sugars extraction, which is linked to the sparging liquor volume flowing through the porosity of the filtering cake. At the opposite of the theory, phenomena of molecular diffusion are limited. Sparging at higher flowrate does not reduce extract recovery.
- A "background" extraction of various molecules, which was observed by the analyse of last runnings during trials with extended sparging. This extraction has been evaluated at 0.3- 0.4°P in our pilot operating conditions.

Practically, assuming that the pressure is not a restrictive parameter, the best way to reduce the sparging time is to raise the sparging flowrate. We showed that a higher sparging flowrate does not reduce extract recovery. Moreover, this would limit the extraction of unwanted compounds from the filter cake. Cycle time reduction and wort quality improvement go in the same direction.
Also, the sparging liquor composition, notably the pH and addition of antioxidants, is a tool to be considered for optimisation of beer flavour stability.

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