Recovery of beer from surplus yeast - System comparison of the separation technology used

W.-D. Herberg*

In beer production, yeast occurs as a by-product, which contains a lot of valuable beer that, however, cannot be reused in the process. Different separation technologies are used for the recovery of this beer, which are set out below.

Process overview

Beer production can be divided into three main process steps:
1. For the production of the beer wort, the starch of the malt or other starch sources must be converted into soluble sugar. In the area of the purity law, this takes place by the malt-inherent enzymes, and outside this, synthetic enzymes are also used. After separating the husks of the starch sources (e.g. malt) and boiling with hops, one obtains the wort that essentially consists of water, sugar, some proteins and minerals, as well as flavourings, colours and aromatic substances.
2. The wort is fermented into beer with the addition of yeast. This produces alcohol and CO₂ from the sugars. Besides these main products, the yeast also forms aromatic substances, like for example higher alcohols, esters, organic acids etc., that influence the beer quality as well as the digestibility. The brewer has a big influence on this spectrum through the choice of the fermenting parameters (temperature, oxygen content, yeast concentration, pressure, wort composition, yeast strain). About one third of the extract of the beer wort remains unfermented; this so-called residual extract consists of polysaccharides, like for example glucans, proteins and minerals. The (bottom fermented) yeast settles at the end of the fermentation and is partially recycled. This fresh yeast from the fermentation is known as fresh yeast in the specialist language.
3. The beer is stored cold, filtered and is then bottled. Through the cold storage and the pH drop during fermentation, trub occurs that settles with the yeast and forms the so-called tank bottoms. Filtration as a final process step before bottling removes all yeast cells, trub particles and also colloidal ingredients.

Yeast mass balance in the fermentation of the beer

To keep the yeast population young and thus vital for fermentation, a certain increase of the yeast is desirable. The yeast can work aerobically (respiration) and also anaerobically (fermentation). During respiration, the energy gain is clearly higher and with it also the growth rate. This growth rate can be controlled through specific ventilation of the yeast or the wort at the beginning of the fermentation. Typically, approx. 20 million cells/ml are metered into the beer and a three-fold growth rate is aimed at. Thus at the end of fermentation, there results a maximum yeast cell count of approx. 80 million/ml, of which 20 million/ml are then usually reused.

The solid matter content of yeast and/or the beer content of a yeast suspension can be determined in several ways:
1. The dry substance (DS) indicates what amount of residual material remains behind after drying at e.g. 105 °C. At this temperature, only water and alcohol are evaporated and the residues of the organic and inorganic substances remain behind. A differentiation between dissolved and undissolved substances is not possible. The result is indicated as % DS. The main possibility of error here is the dissolved extract of a liquid, and so, for example, a clear lemonade with 11 % sugar content by weight has a DS of 11%, without including any solid matter.

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Typically, the following applies: 40 million cells/ml = 1 % by vol. = 0.25 % DS.

The quickest, easiest and closest procedure to the actual process method is the centrifugal sample, which also allows the easiest yield calculation.

The above-mentioned figures mean that 60 million cells/ml correspond to a yeast concentration of 1.5 % by vol. If the tank bottoms occur as a suspension with a yeast concentration of 50 % by vol., this suspension corresponds to approx. 3% of the produced beer (output) of a brewery.

**Characteristics of white yeast**

The solid matter concentrations of white yeast lie in the range of 40-70 % by vol., corresponding to about 10 – 17 % dry matter. It has a pleasant fresh smell, contains a lot of CO₂, is very sticky and has a complex flow behaviour. In the laboratory centrifuge, it is deposited clearly, but is compacted during prolonged centrifugation so that identical centrifuging times must be kept for the comparison of different samples. Through its white colour and high vitality, it is a valuable resource as a base material in the food industry.

**Characteristics of tank bottoms**

In contrast to the rather homogeneous white yeast, a 3-fold layering of the sediment under a turbid supernatant often appears during centrifugation of the tank bottoms:
1. A lower dark layer of hop resins and dead yeast cells
2. A brighter middle layer that is similar to the white yeast
3. A dark layer over this that consists of fine trub particles.

With the tank bottoms, the concentration varies in the range of 5-60 % by vol. which is a challenge for the separation technology used in conjunction with the bad clarification capacity and the inhomogeneity. On average, one can assume solid matter concentrations of 25%. Because of its dark colour, tank bottoms are rarely used in the food processing industry, but they are in demand as high quality feedstuff.

White yeast often needs dilution with de-aerated water before being fed into a beer recovery system:
1. Concentrated yeast with more than 40 % by vol. makes high demands on the processing. These are reduced through the improvement of the flow properties.
2. The water dilutes the liquid surrounding the yeast cells, whereby alcohol and residual extract diffuse from the cell because of the concentration gradient. Thus the yield of the process increases.

The performance information in the following process comparison refers to a concentration of 50 % by vol. of releasable materials in the incoming yeast suspension.

**Yield calculation**

The yield of the processes can be determined in different ways. The simplest and thus the most accurate is the analysis based on the centrifugal samples with the laboratory centrifuge. If one looks at the yield of a system, in principle the following applies:

\[
\text{Yield} \% = \frac{\text{Mass of the outbound extract}}{\text{Mass of the inbound extract}} \times 100
\]

Or

\[
\text{Yield} \% = \frac{\text{Volume out} \times \text{extract concentration out}}{\text{Volume in} \times \text{extract concentration in}} \times 100
\]

Hence, one determines the volumes and the extract concentrations of the two streams:

Feed: \( Volumes \times \text{Proportion of liquid phase} \times \text{Concentration} \), in the Fig. 3 example with a volume flow of 10 hl/h:
\[ 10 \text{ hl/h Yeast} \times 50\% \text{ Liquid proportion} \times 12 \text{ kg/hl Extract} = 60 \text{ kg/h Extract flow rate} \]
Outlet: \( 4.75 \text{ hl/h Beer} \times 12 \text{ kg/hl Extract} = 57 \text{ kg/h} \)
This results in a yield of 95%. This would be a typical yield of a centrifuge operation without diluting the yeast in the inflow.
If the yeast is diluted 2:1 with water before the centrifuge, the feed conditions remain unchanged. However, the outlet side changes drastically through leaching of the extract from the yeast cells:

9.75 hl/h Beer-Water mixture x 7.4 kg Extract/hl = 72.15 kg/h Extract.

This corresponds to a yield of 120%. This is also a typical value for the practical use of a self-cleaning separator and yeast dilution in the inflow.

**Economic efficiency of a beer recovery system:**

The installations amortise very quickly. An example is a brewery with 2 million hl/a annual output, wherein a system should perform about 20 hl/h for the coverage of the seasonal peaks:

A 3% yeast proportion of the annual output results in an annual consumption of approx. 60,000 hl of yeast. Typically, about 25,000 hl/a of beer are recovered from the yeast.

With a beer value of 15E/hl, 375,000 €/a can thus be generated. Depending on the scope of the integration effort and, depending on the selected system, the investment lies in the range of 400,000 – 800,000 €. This means that the ROI can amount to one year in the best case. So beer recovery systems are very economical.

Minor transport costs must be added for the concentrated surplus yeast, which is used in food processing industries or agriculture.

**System for beer recovery**

Besides belt and chamber filter presses that are no longer commonly used, the usual methods are centrifugation or filtration.

**Self-cleaning separators**

Self-cleaning separators combine simple process management with a good yield. The yeast is fed to the separator from a buffer tank. Because of the high solid matter proportion of the yeast
solid matter concentration of 95 % by vol. When using GEA, solid matter volume. Performance control is done per machine lies between 3 hl/h - 25 hl/h of tank bottoms, the turbidity is clearly the clear phase, and in the pure processing white yeast, low turbidity is achieved in 90 - 150 s, in order to achieve the clarifying area of 90 - 150 s, in order to achieve the performance per unit is high, even when using relatively small machines. The machine illustrated in Fig. 5 performs up to 50 hl/h with a bowl diameter of only 540 mm and with this has a power consumption of approx. 40 kW. The clarifying efficiency is on a par with that of the self-cleaning separators, but the achieved solid matter concentration of the separated yeast is clearly lower at approx. 80 % by vol.

**Decanters**

Decisive progress in decanter construction with respect to oxygen pick up and hygienic design allows the application of decanters for beer recovery. Decanters that have a much smaller clarifying area than disk-type separators are ideal for the processing of high solid matter volumes. With white yeast, the performance is high and the clarification good, because the yeast cells sediment well. However, with tank bottoms almost no protein is separated which results in very turbid and indeed yeast-free clear phases, but still with solid content. Post-clarification is recommended by means of a separator. The concentration of the separated yeast lies at about 95 % by vol. Decanters are the only system with which the yeast in the feed does not have to be diluted.

With all centrifugal processes, the beer has a residual turbidity and contains small amounts of yeast. However, depending on the point of return into the system, this is insignificant since the beer is usually blended back before fermentation or during the transfer from fermentation to storage.

**Cross-flow Filtration**

For beer recovery, systems with ceramic elements have prevailed, not least because of their superior durability and easy cleaning. There are only a few systems with polymer flat membranes. The systems are equipped with multi-channel elements, and 6 mm or better 8 mm channels, are used because of the high viscosity of the yeast. The pore width used is 0.2 - 0.8 μm, but the influence of the pore width on the clarity of the product is low. The filtrates are free of yeast and largely sterile. Because fine turbidity is also retained, the blending into the beer can take place during the filtration. Through this, the imputed value of the recovered beer increases somewhat. The electric power input for a system of approx. 25 hl/h inflow performance is about 60 kW.

**The membrane systems are operated in three variants:**

1. Continuous operation: The suspension is supplied and concentrated in the filtration loop, and the concentrate is continuously discharged. This leads to short dwell times of the yeast in the system, but it is always filtered with maximum concentration so that the flux is low and the power input is high. Because the concentrate still contains undiluted extract, the yield is low.
2. Continuous operation with dilution of the yeast in the inflow: like 1, but through the water addition in the inflow, the losses decrease because the extract was diluted in the concentrate.
3. Batch process with diafiltration: a batch tank is concentrated via the filtration loop. If the final concentration is reached, the mixture is diluted with water. This variation achieves the best yields, but the process duration is approx. 20 h.

In the processing of pure tank bottoms, there can be shorter operation times of the membranes between the cleanings, because the pores of the membranes become blocked through the fine trub. However, the general service life of ceramic membranes is virtually unlimited.

**Comparison of the systems**

For the system comparison, there are four aspects in the foreground:

1. **Product quality:**
   a. In taste, the systems are comparable in the blends (max. 3% dosage of recovered beer)
   b. Turbidity: the dosage of yeast beer from the centrifuge processes directly before the beer filtration can influence the turbidity of the filtrates, and so the blending should be done earlier. This effect does not appear with yeast beer from membrane systems.

2. **Integration expenditure:**
   a. Membrane systems need their own CIP (purification plant) and centrifuges are cleaned together with the conduit.
   b. Separators need little space
   c. For the integration of decanters, post-clarification through separators is recommended

3. **Operating mode:** In the processing of mixtures of yeast and tank bottoms, membrane systems work better than for tank bottoms processing alone. The sales yeast thus obtained can be difficult to use as a food base material. This also applies to a lower extent for nozzle separators.

4. **Operating costs:** The use of nozzle separators is the best solution. The running costs (electricity, cleaning) of membrane systems are above those of centrifuges, but the latter have higher maintenance costs. Because centrifuges are produced only in graduated sizes, the investment costs of certain system sizes can speak respectively for one or other system.

**Summary:**

With beer recovery systems, approx. 1-2% of the annual output of a brewery can be economically recovered from the yeast. The established systems are centrifuges and ceramic cross-flow filtration. If clear filtrates are required, cross-flow filtration is used, which requires separate CIP in addition. Nozzle separators offer high performance with low investment. Simple installation, maximum yield and great flexibility can be combined with the installation of self-cleaning separators. A detailed analysis of local conditions is required in each case.