Filtration technology for beer and beer yeast treatment

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Abstract. Solid-liquid filtration processes are crucial for the production of beer. Clarification of the green beer generates a clear and bright product with extended colloidal and microbiological shelf life. Conventionally, clear filtration is based on pre-coat filtration using filter aids, such as diatomaceous earth (Kieselguhr). However, the application of Kieselguhr requires strict adherence to occupational safety and health protection, as it is classified as a hazardous substance by the World Health Organisation and can lead to lung diseases. Furthermore, significant amounts of waste filter aids are generated. An alternative to pre-coat filtration is microfiltration that avoids the generation of hazardous wastes. Microfiltration can also be applied in beer yeast treatment. This article highlights major concepts and restriction of the filtration processes.

1. Introduction
Beer is one of the most popular beverages in the world. In the alcoholic drinks market, beer forms the biggest segment: In 2019, it accounted for 40 % of the market with a total revenue of about US$651 billion and beer production of about 190 billion liters. From 2019 to 2025, the worldwide beer volume sales is expected to increase annually by 0.4%. In Europe, the UK was the country with the highest revenue in the beer segment, followed by Germany and Russia [1].

The production of beer involves several physico-chemical and biochemical reaction steps that are interconnected by intermediate solid-liquid separation steps. The first step is the mashing of the malted and grinded grains in hot brewing water. During mashing, water-soluble sugar is enzymatically produced out of starch and subsequently dissolved in water. Furthermore, proteins are solubilized [2]. Subsequently, dissolved and undissolved components are separated (lautering). This creates the wort, which is then concentrated by boiling. During boiling, proteins are glycated and partially coagulated. The coagulated proteins are separated from the wort as hot trub [2].

After cooling, the wort is transferred to fermentation tanks where yeast is added. Main task of the yeast is the conversion of the grain sugars to alcohol and carbon dioxide within several days. The resulting liquid, so called green beer, is filtered to remove the yeast residue and transferred to the storage cellar to mature. During fermentation and maturation processes, protein aggregation takes place as well [2] and can be removed/filtered out together with remaining yeast cells.

Several factors have a significant effect on the economy of the brewing process, s. also figure 1:

- Rising energy and raw material costs.
- Efforts to guarantee product quality.
- Efforts to ensure process safety and occupational safety.
• Influence of market trends: In addition to a general trend in the society to healthier lifestyle, the COVID-19 pandemic led to a severe decline of the sales markets [1].

• Compliance with environmental requirements: Requirements to combat climate change, to improve water quality and to cope with waste disposal increase the production costs. Especially, legislative demands concerning waste disposal have become more stringent during the last years.

Fig. 1. Fields of tension in the brewing industry

The quality of the generated beer depends on several measurable parameters, such as pH, colour, turbidity (haze), foam appearance, total phenol and ethanol contents, real and original extracts and flavour [3], [4].

The origin of beer turbidity can be microbial cells or colloidal particles of biological and mineral origin. To achieve colloidal stability, non-microbial turbidities and their precursors need to be removed to prevent haze formation after beer packaging. The prevention or removal of non-microbiological haze can be considered a specific challenge to the brewing industry [5].

2. Beer filtration technology
The aim of beer filtration is the retention of solid particles (such as yeast cells, macrocolloids, and suspended matter) and solutes that cause haze formation. Filtration behaviour cannot be predicted due to the variety of compounds (chemical diversity, large size range) which need to be retained [6].

It is well known that filterability is strongly depending on the β-glucan content in beer [7], [8]. β-glucans are polymers (polysaccharides) that occur in beer as degradation products of yeast and cereal cell walls [9], [10].

Especially, the amount and molar mass distribution of β-glucan is a decisive parameter for the filterability of beer [11]. According to Leedham et al., the β-glucan content in beer ranges from about 0 to 3.95 g/L [12]. β-Glucan polymerization results in an increase in the beer viscosity [13]. Spontaneous and shear inforced gel formation of β-glucan [14], [5] may contribute to the increase of the filter resistance.

Furthermore, Speers et al. state that filtration with 0.45 µm membranes removed only very small amounts of the hazes caused by β-glucans [5].

The main aims of filtration are the removal of any remaining yeast cells, precipitated proteins, dex- trins, β-glucans, and polyphenol materials in order to re-duce beer haze to levels acceptable to consumers and to prolong its shelf-life [15].

In general, three different approaches of beer clarification can be distinguished: dead-end filtration (pre-coat filtration), crossflow and dynamic microfiltration filtration, s. figure 2.
2.1. Pre-coat filtration
Dead-end filtration based on filter-aids - also referred to as pre-coat filtration - has been the standard in beer filtration for more than 100 years [16].

Generally, pre-coat filtration is based on the addition of filter aids, prepared as a slurry, to the beer that needs to be filtered. The resulting suspension is introduced perpendicular to the filter area (support). Thus, together with yeast and other beer components a loose filter cake is build up that allows an economic flux. Based on the selected filter aids, the filter efficiency can be described by a combination of depth filtration, surface filtration and adsorption.

2.1.1. Filter aids. In pre-coat filtration for beer clarification, different filter aids are combined. The characteristics of commonly employed filter aids are depicted in table 1.

| Table 1. Characteristics of filter aids commonly employed in beer clarification. |
|-----------------|-----------------|-----------------|
| Origin          | Kieselguhr      | Perlite         | Fibrous filter aids |
| Shape           | Fossilised algae| processed volcanic rocks | Cellulose             |
| Structure       | Irregular       | flat, even particles | Fibrous particles   |
| Function        | Large inner surface | Non-porous      | Interconnection of the filtercake |
| Rejection       | Small particle  | Medium size particle | Slimy substances    |

Specifically, pre-coat filtration comprises several steps:

- Precoating denotes the application of the filter aids onto the support until the support is fully coated. For this, a suspension based on brewing water and filter aids is fed into the filter system.
- Body feed: A specific amount of filter aids slurry is constantly added to the green beer and fed into the filter system. Constantly, a filtercake is build up, which allows extended filtration times, as blocking of the generated pores is prevented [17]. Body feed addition can be adapted to changing feed characteristics (e.g. changing of tanks during a filtration process that lead increasing flow resistance of the filter cake).
- After the limiting pressure of the filter system is reached, the filtration process is stopped, the remaining beer is drained and the generated filter cake is removed by backwashing.
Table 2 shows typical performance parameters of pre-coat filtration.

**Table 2.** Typical performance parameters of pre-coat filtration.

| Parameter                  | Value                  |
|----------------------------|------------------------|
| **Filter system**          |                        |
| Area                       | 5-150 m²               |
| Average filtrate flux      | ~ 0.15 m³/m²h          |
| Filtration time            | 5-20 h                 |
| **Pre-coating**            |                        |
| Amount of Kieselguhr       | 600-2,000 g/m²         |
| Suspension density         | 10-15 wt.-%            |
| **Body feed**              |                        |
| Amount of Kieselguhr       | 0.1-10 g/L beer        |
| Suspension density         | 10-15 wt.-%            |

2.1.2. *Rejection mechanisms.* Component rejection in pre-coat filtration can be explained by the following mechanisms:

- Surface filtration: Sieve effect. Beer components are rejected at the outer layer of the filter cake due to size exclusion.
- Depth filtration: Beer components are incorporated in the formed filter cake.
- Adsorption: Especially, Kieselguhr allows the adsorption of dissolved beer components.

The rejection mechanisms of pre-coat filtration are depicted in figure 3.

**Fig. 3.** Rejection mechanisms of pre-coat filtration

2.1.3. *Filter systems.* In practice, three major system designs of supports, incorporated in a pressure vessel, are applied [17]: plate-and-frame filters, in which the support is a cloth or a filter sheet, horizontal leaf or vertical leaf filters, in which the support is a wire mesh and candle filters, in which a long thin perforated pipe supports the filter aids. In all applications, the unfiltered beer enters the pressure vessel in a single pass and permeates through the filter cake that has formed on the support [17].

Fig. 4-5 schematically depict the different concepts of pre-coat filters. Fig. 4 shows the scheme of a plate-and-frame filter.
Fig. 4. Scheme of a plate-and-frame filter.

Fig. 5 shows the scheme of a leaf filter.

Fig. 5. Scheme of a leaf filter.

Fig. 6 shows the scheme of a candle filter.
2.1.4. Advantages and disadvantages of pre-coat filtration. Generally, the main advantages of pre-coat filtration are the simple design of the filtration apparatuses and the easy adaptation of composition and amount of filter aids to the respective demands of the filtration process (pressure drop as a function of time).

These advantages are offset by following disadvantages:

- Due to the application of filter aids as water based suspensions, the water consumption of pre-coat filtration is high. This is not only an economic question, but also an environmental issue [16].
- The application of pre-coat filtration consumes large quantities of the finite resources Kieselguhr (s. table 2) [16].
- Spent Kieselguhr sludge is classified as a hazardous waste (due to the included crystalline silica) [16].
- Handling of Kieselguhr requires the compliance with safe working conditions, as Kieselguhr is is harmful to health and considered to be carcinogenic [17]. There is the possibility of irreversible damage by inhalation [18].
- The formation of hazardous waste products may impair the marketing image of beer as a natural product [16].

Accordingly, efforts were directed towards the substitution of pre-coat filtration by more environmentally friendly processes, such as membrane filtration.

2.2. Microfiltration

Microfiltration is a pressure driven membrane process. The applied membranes are porous and can separate particles or macromolecules with sizes between 0.1–10 µm from solutions. Due to the chemical and thermal stability, common membrane materials employed in beer clarification are ceramics and polyethersulfone (PES). In order to compete with pre-coat filtration using filter aids, MF should have following characteristics:

- Production of a clear and bright beer with similar quality.
- Separation in a single-step without using any additives.
- Operation at low temperature (0-2 °C)

Fig. 6. Scheme of a candle filter.
• Operation at an economic flux.

2.2.1. Fouling. The rejected substances may interact with the membrane and lead to a change in rejection and to a substantial decrease of filtrate flux (fouling).

Fouling of membranes is a consequence of different effects, such as the build-up of a filter cake, blocking of the membrane pores by particles, and adsorption of macromolecules in the pores, which gradually decreases the effective pore diameter, s. figure 7 [19], [15].

![Fouling mechanisms of porous membranes](image)

**Fig. 7:** Fouling mechanisms of porous membranes.

Fouling is the critical factor in most filtration processes that can limit the application of microfiltration for beer treatment [19].

According to Cimini et al., the average molecular mass of β-glucans and arabinoxylans should have a stronger negative impact on beer filterability than the concentrations of these substances [20].

Investigations performed by [21] showed particle sizes of β-glucan aggregates in the range of 131 ± 18 μm. Arabinoxylans showed a bimodal distribution, with small aggregates of 9 ± 1 μm and bigger size aggregates of 147 ± 9 μm.

According to examinations done by Stopka et al, cake formation mechanism is a dominant fouling mechanism in microfiltration of yeast [19].

According to Stopka et al. [19], there are several approaches to reduce fouling effects by inhibiting the interaction of deposited substances with the membrane: hydrodynamic manipulations, membrane surface modification, and regular backflushing / cleaning. Cimini adds enzymatic pretreatment [20].

Cimini et al. state that the presence of tanno-protein colloidal particles in the green beer represented the main limiting factor for CFMF performance and beer quality [20].

Experimental investigations of Fillaudeau and Carrère based on tubular ceramic membranes with 0.10, 0.45, 0.80, and 1.40 μm nominal pore size type KERASEP from Rhodia-Orelis (zirconium–titanium oxide on an aluminium–titanium oxide support) revealed that the fouling mechanism depends on the mean membrane pore size (cut-off). Yeast resistance was the predominant fouling mechanism of the membrane with a cut-off of 1.4 μm. There was a strong influence of the cross-flow velocity on the flux. On membranes with cut-off <1 μm a less compact surface layer controls the filtration process. The authors conclude that for clear filtration of beer, membranes with pore sizes >1 μm should be used because of the higher permeate flow rates and the low retention of essential beer compounds [6].

Yazdanshenas et al. report about the investigation of tubular ceramic membrane with nominal pore size of 0.45 μm for the filtration of green non-alcoholic beer. They conclude that microfiltration is controlled by the formation of surface layer on the membrane. Accordingly, hydrodynamic techniques should play a significant role in improving the performance of the process [22].

2.2.2. Crossflow filtration. In crossflow filtration, the suspension flows tangentially to the membrane surface. This leads to shear forces that sweep the particles toward the module exit. Accordingly, the surface cake layer remains relatively [19].

The performance of crossflow microfiltration is strongly influenced by the feed turbidity [20].

About two decades ago, polymeric membrane systems based on polyethersulphone (PES) were introduced into the market. Advantages of hollow-fiber systems are a high packing density, a relatively low-power consumption, and mechanical strength to withstand back-flushing procedures [23].
To remove larger suspended particles, such as yeast cells and other haze-forming compounds, Pall/GEA Westfalia [24] and AlfaLaval/Sartorius [25] designed hybrid processes using centrifugation as a pre-treatment and microfiltration as the main treatment, whereas the Norit system [26] waived the centrifugation, s. table 3.

Table 3. Large-scale microfiltration systems for beer clarification based on polymeric membranes (PES).

| Membrane material | Pall / GEA Westfalia | AlfaLaval / Sartorius | Norit |
|-------------------|----------------------|-----------------------|-------|
| Pre-treatment     | centrifuge           | centrifuge            | -     |
| Membrane type     | Hollow fiber         | Flat sheet cassette   | Hollow fiber |
| Nominal membrane cut-off | 0.65 µm     | 0.6 µm                | 0.5 µm |
| Plant size        | 20 – 500 hl/h        | 20 – 500 hl/h         | 10 – 1,200 hl/h |
| Crossflow velocity| 1.1-1.5 m/s          | 2 m/s                 |       |

Cimini and Moresi state that the average beer filtrate flux through polyethersulphone hollow-fiber membranes is only about one fifth of that (250-500 L/(m²h)) achievable with DE filters [23]. Recently, the feasibility of tubular ceramic membrane systems is discussed, as the advantage over polymeric hollow fiber membranes is extension of the membrane lifetime from two to ten years and the higher flux achieved [22], [23]. Cimini and Moresi applied relatively high crossflow velocities between 4 to 6 m/s in the absence of CO2 backpulsing. With CO2 back-flushing applied every 50-60 min, the crossflow velocity could be reduced to 2.5 m/s [23].

Furthermore, Cimini and Moresi expect that a novel process using centrifugation as a pre-treatment and crossflow microfiltration with ceramic hollow fiber membranes might an effective alternative to the current beer conditioning techniques based on DE filtration and PVPP treatment [27].

2.2.3. Dynamic filtration. Shear forces are the key factor for microfiltration performance. However, the combination of high feed pressures and flow rates in crossflow filtration requires powerful and expensive pumps that consume much energy. An alternative for the decoupling of the shear rates from large feed flow rates and resulting pressure drops is dynamic filtration. Different technical concepts for dynamic filtration exist, e.g. rotating modules using organic/ceramic disk membranes, vibrating modules and shear forces induced by impellors close to the membrane surface [28].

According to Fillauudeau et al. [16] dynamic filtration devices have been reported by following manufacturers: Artisan Industries, ABB-Flootek, Spintek, Komline-Sanderson, Hitachi, Pall.

A general drawback of dynamic filtration is the technical complexity and higher costs moving parts and sealings. Furthermore, membrane area of most systems is restricted.

3. Comparison of the concepts
Table 4 sums up the characteristics of the described beer clarification concepts.
Table 4. Comparison of the technologies employed in beer filtration.

|                        | Pre-coat filtration | Crossflow MF | Dynamic MF |
|------------------------|---------------------|--------------|------------|
| Separation principle   | Combination of depth filtration, surface filtration and adsorption | Surface filtration and cake filtration | Surface filtration and cake filtration |
| Required additives     | Filter aids: Kieselguhr Perlite Cellulose | no | no |
| Filter medium          | Cartridge filter Plate filters | Polymeric and ceramic MF membranes | Polymeric and ceramic MF membranes |
| Pre-filtration         | Not required | Advisable | Advisable |
| Flexibility to changing beer characteristics | Very high, due to adaptation of filter aids during the running process | no | no |
| Function               | Enforced formation of a surface layer, in which the separated particles are incorporated | High fluid velocity to reduce the thickness of the filter cake formed on the membrane surface | Relative movement between membrane and feed solution induced by rotation, vibration or impellers, shear force independent of the feed flow rate |
| Technical efforts      | Moderate to high according to the chosen filter design | Moderate to high: Pre-treatment advisable, but utilisation of standard membrane modules | High, due to sophisticated module design |
| Waste formation        | Retentate is a hazardous waste | no | no |
| Health impair during handling | possible | no | no |

4. Yeast filtration
Brewer’s spent yeast (BSY) – also referred to as surplus yeast - is a typical by-product of the brewing process. The spent yeast cells are removed from storage tanks and fermentations tanks [29].

According to VLB Berlin, 15 to 18 tons of BSY are produced per 10,000 hL of finished beer [30]. BSY cannot be disposed of into wastewater streams without prior treatment, as its high COD value would have a negative effect on the environment [30].

BSY solutions contain about 2 – 3 % of the whole beer production of a brewery. A recovery of more than 50 % of the beer contained in the yeast is economically and technically feasible. The quality of the recovered beer depends on the storage conditions of the surplus yeast (storage time, temperature, contact to O₂) and is decisive for the blending location, e.g. blending with fresh beer or addition to the wort in the brewhouse. The separated and concentrated yeast can be utilised in animal food as a low-cost source of protein [29], as an additive in the food industry [31] and in cosmetics and pharmaceutical production, s. figure 8.
According to Bock and Rögener [32] several parameters, such as brewery size, available space, dry matter of the excess yeast, investment costs, running costs or quality of the recovered yeast, are decisive for the selection of an appropriate treatment system. The separation of beer from a surplus yeast solution can take place with a crossflow membrane system based on ceramic membranes. To increase the extract and alcohol recovery, the plant can be operated with the addition of a certain amount of water, once a specific concentration of the yeast is gained (diafiltration) [33].

5. Conclusions

Clear filtration for the removal of yeast and turbidity forming substances is a process step that determines the beer quality. Traditionally, dead-end filtration with filter-aids (pre-coat filtration) has been the standard, due to relatively high fluxes and the possibility to react to changing process condition. However, these processes generate huge amounts of hazardous wastes that need to be landfilled.

Microfiltration systems are an alternative, as they do not generate waste products. At first, polymeric hollow fiber membranes were introduced to the market. They showed significantly lower filtrate fluxes compared to pre-coat filtration. In the moment, tubular ceramic membranes seem to be the solution to overcome the drawbacks of the previous systems.

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