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Beer Filtration using Cellulose Fibres – a Review

Presently, kieselguhr filtration of beer is the most commonly used technology worldwide. Due to the growing problems with this filter aid, mainly concerning worker health and kieselguhr disposal, many alternatives have been investigated. Especially small and medium-sized breweries need solutions that allow existing equipment to be retrofitted. In the last decades, occasional articles treating the filtration of beer using cellulose fibres have been published. The properties of filter aids consisting exclusively of cellulose have been investigated as well as the properties of mixtures of cellulose and other filter aids. A lot of knowledge has thus been acquired. As a result of a systematic analysis of the existing literature on the topic, the important properties of cellulose-based filter aids are presented. Pre-coat filtration of beer by cellulose is possible. The beer has to be well pre-clarified. An economic technology, which would have to include a multiple regeneration of the filter aid, could not yet be found. Possible starting points for future investigations are named.

Descriptors: cake filtration, cellulose, regeneration, beer

1 Introduction

Beer has been filtered using cellulose fibres since the beginning of industrial filtration, when clarification by chips, strainer bags or gluey agents was no longer regarded as sufficient [1]. This began in 1879 with the appearance of Enzinger's first filtration device and was continued successfully over a long period of time by the pulp filtration. With these filter systems, regenerable filter media were already in use. In the meantime, pulp has been replaced almost completely by diatomaceous earth even though cellulose is still the main component of filter sheets for polishing or sterile filtration of beer and of modern sheet substitutes [2, 3]. Cellulose fibres have been in use as a supplementary filter aid for the filtration by kieselguhr for decades. They ensure a better binding of the pre-coat to the filter medium, a mechanical stabilizing of the filter cake against pressure shocks, and an easier removal of the cake from the medium after filtration [4].

Since the 1980s, ultra-pure alpha-cellulose has been used in filtration processes of wine, juice and cider. In addition, it has proven its worth in filtrations in the production of sugar, dextrose and pectin, in the chemical industry, in wastewater treatment and in other filtration processes [5, 6].

The motive for the modern research on the pre-coat filtration by means of cellulose is to be found in another technology. The beer filtration using diatomaceous earth is well-established and employed successfully throughout the world. Calcined and fluxcalcined kieselguhrs contain up to 20-25 % silica as quartz and up to 30 % as cristobalite and fluxcalcined kieselguhrs are comprised of up to 45 % cristobalite. Quartz and cristobalite in kieselguhr are small enough to be inhaled. When inhaled, both forms are classified as carcinogenic (carcinogenicity group 1) in humans by the International Agency for Research on Cancer (IARC) [7, 8]. Although cristobalite is dangerous only when inhaled, this classification creates problems for the use of kieselguhr in the brewery, for the disposal and for public image [9]. Because of the uncertainty among users and consumers, great efforts have been undertaken since the 1980s to replace the kieselguhr pre-coat filtration of beer with respect to quality and economy [10].

Some papers deal with the reduction of cristobalite contents in calcined and fluxcalcined kieselguhrs. By varying the fluxing agent concentration, calcination temperature and time, it is possible to reduce the formation of cristobalite. Unfortunately, complete avoidance is still not possible without a correspondingly large decrease in permeability [11, 12].

The recycling of spent kieselguhr as an additive to fertilizers is becoming increasingly difficult due to German legislation, for example: Bioabfallverordnung [13] and Düngeverordnung [14]. Storage of kieselguhr sludge is problematic due to the rapid decomposition of organic components [15, 16]. Adding spent kieselguhr to spent grains is prohibited by the Futtermittelverordnung [17] and discharging with waste water is discouraged by most communal codes in light of solid matter loads [7]. Currently, the regulation "Verordnung über die umweltverträgliche Ablagerung von Siedlungsabfällen" [18] in Germany allows land-filling of untreated spent kieselguhr sludge only in sites of group III which are commonly called special waste disposals. Due to high costs, this method of discharge is uneconomical [19].

In spite of many efforts to recycle kieselguhr, cost effectiveness could not be proven neither by wet [20, 21] nor by thermic [22, 23, 24] processes [25].

There are established alternatives in the brewing industry, e.g. the cross-flow filtration. These, however, are not suitable for every brewery. Especially producers of a wide range of beer styles with frequent product changes and those that are confronted with a

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greatly varying quality of unfiltered beer suffer from a lack of economical alternatives [26, 27].

With this as a background, the following gives a synopsis of the relevant properties of cellulose fibres that have been published thus far.

2 Available Celluloses

Cellulose is the major component of vegetable cell walls and thus the most important organic matter in nature. Fengel estimated the worldwide amount of vegetable cellulose at $2.7*10^{11}$t [28].

Cellulose is a linear isotactic β-1,4 polyacetal with the basic chemical formula $(C_6H_{10}O_5)_n$. The base unit is cellobiose, which consists of two molecules glucose. Depending on the origin, the degree of polymerization (i. e. units of glucose) is between 7,500 and 15,300 [29]. Alpha-cellulose is defined as the fraction with a degree of polymerization of over 200 and is insoluble in 17.5 % and 24 % caustic and potassium hydroxide, respectively [28].

Degradation of cellulose in concentrated acids begins at temperatures below 100 °C. In caustic solutions, hydrolysis proceeds at a significant rate at temperatures above 150 °C. Cellulose is insoluble in water and in dilute acids. It is relatively hygroscopic [30]. In contrast to kieselguhr, perlite and asbestos, cellulose swells in water [31].

In central Europe coniferous wood such as spruce and fir as well as wood from deciduous trees such as birch and beech are available as suppliers of raw material for the production of ultra-pure alpha-cellulose fibres needed for filtration purposes. The beverage industry uses exclusively beech fibres, as only these possess the necessary neutrality with regard to the flavour of the final product. The herbal cell walls never contain cellulose in pure form; it is always combined with differing shares of polyoses, lignin and other substances. These “contaminations“ must chemically be brought into solution [6, 32]. Especially in wood cellulose, there are close combinations, thus intensive chemical procedures are necessary to isolate the cellulose [28]. In nature, cellulose molecules never exist as a single chain but rather as many chains combined in a crystalline order [29]. Ultra-pure alpha-celluloses that fulfil the criteria of sustainable forestry of the FSC (Forest Stewardship Council) are available on the market [33].

One distinguishes between cellulose flour and fibrillated fibres. Fibrillation refers to splitting of the fibres parallel to the fibre axis. Fibrillated fibres have numerous partial splittings on the surface. Fibrillation is usually done mechanically, but may also be achieved enzymatically [34, 35].

3 Conditions for Pre-coat Filtration

Classification of Methods

During cake filtration, solid particles settle on the filter medium as a growing cake, which provides the actual filtration effect [36]. With its growth, the flow resistance rises or the velocity decreases. The dead end filtration is thus a non-stationary and periodic process [37].

The following variations are possible [37]:

- with pre-coat: mainly for particles, which are smaller than the pores of the filter medium;
- without pre-coat: mainly for particles, which are larger than the pores of the filter medium;
- without body-feed: for non-deformable particles that build up a cake which prevents the filter medium or the pre-coat from clogging;
- with body-feed: for deformable particles, which have to be deposited in the growing cake such that enough pores remain open;
- continuous, e.g. in vacuum drum filters;
- discontinuous, e.g. in powder filter presses.

During cake filtration, particles settle on the actual surface of the cake, thereby continuously renewing the surface. This is actually surface straining filtration with a continuously changing surface [38, 37]. The properties of the suspension and of the chosen filter aid determine whether particles enter the cake and a separation in the depth of the cake takes place and thus along with a surface filtration with continuously renewed surface, a depth filtration effect occurs [39].

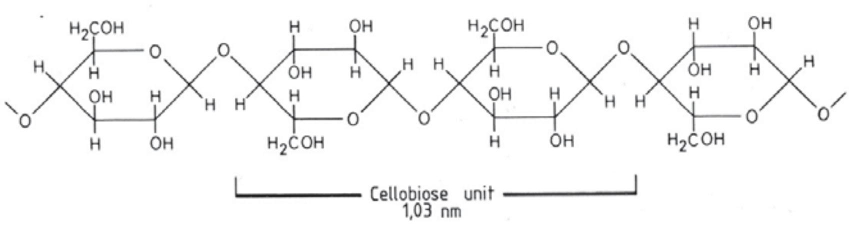

Fig. 1 Section of a cellulose molecule [28]

The separation of particles in depth follows two different principles. On the one hand, particles with dimensions much smaller than the pore diameters that could thus easily pass through the filter are retained by attraction. This effect is called adsorptive filtration. On the other hand, a lot of larger particles get caught in the filter by depth straining filtration. Incomplete moistening of the filter aid particles' surfaces increases the trans-cake pressure drop and must be avoided [40]. Particles can be separated in depth of a filter cake until all possible separating facilities are occupied [41]. The adsorptive mechanism is, in respect of filtration efficiency, flow rate, and separation capacity, superior to the depth straining mechanism [42]. Products must be protected from quality loss by adsorption of valuable components when using deep-effective filter aids [43]. Kieselguhr filtration separates particles mainly on the present surface. Nevertheless, a depth effect is also present [39, 44].

Statements about filter effect and flow rate are always dependent upon the interaction of filter medium, filter aid, and unfiltered liquid properties. Global statements can only indicate tendencies [45, 46, 47].

The particles to be separated in the context of beer filtration are – as is the general case with beverages – of amorphous-fluffy to gel-like structure, partly compressible, and virtually all deformable. Thus, building up a cake without any filter aids is not possible [48, 49]. The separated particles as well as the filter media and the filter aids display a resistance to the product flow [50]. The filter equation derived from the Darcy equation for constant pressure $t = a_1*V^2 + a_0*V$ describes cake filtrations with incompressible filter aids in parabolic form [51].

With pre-coat filtration, filter media and filter aids have to be well-matched [52] in order to allow for operation, which is adaptable to the quality of the unfiltered liquid. Most other kinds of filtration do not offer any flexibility in this respect.

Beer filtration is carried out single- or multi-staged. Mostly, primary filtration and secondary filtration are distinguished. The primary filtration's purpose is to separate micro-organisms and particles to a desired extend. Before secondary filtration, the beer should already be clarified to a solid content of less than 0.1 % dry matter. The secondary filtration is a polishing filtration that aims to control solid particles such as kieselguhr, PVPP, fibres and yeast cells [53]. Beer brightness is measured by light scattering methods and indicated mainly in EBC-units. Of course the success of any filtration is dependent upon the beer composition and in this regard upon the colloid structure [54, 55].

Filter Aids

A filter aid must fulfil the following criteria [22]:

- it has to be food safe;
- it has to be suspendable;
- it has to be pre-coatable;
- it has to be homogenisable.

4 The Precursor: the Pulp Filtration

Pulp filtration uses cellulose fibres as main component of the filter media. These can be regenerated. The filter media are preformed pulp cakes. Initially, the pulp was made of cellulose and rags (waste cotton fabrics), later of cellulose and linters (fine seed fibres of cotton). Adsorptive and depth straining filtration underlie the function of pulp filtration [56]. In order to improve the clarifying effect, fibres were roughened [57]. Pulp dominated the beer filtration for decades.

De Clerck examined the pulp filtration thoroughly in scientific terms [58]. Beer constituent groups differ concerning the adsorption capacity of pulp. Thereby, for example, the first beers of a filter run are brighter than later in filtration when the pulp has to a great extent been fed with colouring substances. He observed similar phenomena with bitter substances, surface-active substances, and extract. Every substance reaches its balance at an individual time.

In 1981 for the first time, a large American brewery applied a newly-developed pulp on the basis of positively-charged cotton cellulose.The adsorptive effect of the formerly used asbestos should be achieved by the modified charge. The results were judged to be positive in respect of flow rate, haze reduction and filtration costs [59].

Advantages of the pulp filtration from today's point-of-view are:

- the regenerable and compostable filter medium;
- the stabilising effect of the adsorptive property.

Appreciable disadvantages are:

- the risk of haze breakthrough if the filtration is not finished in time;
- the poor tolerance of pressure shocks, which can result in haze bleed-through and microbiological contamination;
- the relatively big portions of first and post runnings and as the case might be the accompanying losses;
- the poor tolerance of very hazy unfiltered beers, which lead to quick blocking;
- the labour-intensive and time-consuming method, which is also susceptible to operator-error;
- the investment-intensive equipment for the washing and pressing of the filter cakes;
- the great expenditure of heat and water.

5 Relevant Properties of Cellulose Fibres for Filtration

5.1 Analysed Papers

Several authors have dealt with the pre-coat filtration by means of cellulose. An economic alternative to kieselguhr could not yet be found. *Evers* [49] proved that beer can be filtered by means of regenerated cellulose in single- and two-staged processes. *Zeller* et al. [60] were able to prove this on a two-staged process on horizontal pressure leaf filters using regenerated cellulose. In most articles, mixtures of varying fibre lengths and fibrillation degrees, often with other filter aids, are described.

Evers [49], *Donhauser et al.* [61, 10], *Wackerbauer et al.* [62, 63] and *Liu* [64] described the F&S system, which carried out the pre-clarification either by a separator or by cellulose and the secondary filtration by cellulose and PVPP. Conventional powder filters of different types partly with enlarged bottom distance were used.

In 1990 *Grund et al.* introduced a new filtration procedure for beer, also employing a new type of filter [65]. Instead of a kettle, this filter was constructed of horizontally arranged filter elements that were hung between a ground disk and a lid disk, pressed together by a central spindle. As filter medium there was multilayer gauze welded into the element frames. In this unit, primary, polishing, sterile filtration, or stabilisation could take place depending upon demand. The filter aid employed was composed of highly fibrillated cellulose fibres and kieselguhr-perlite-synthetic-microfibres. The filter cake could remain in the filter for several filtration runs, until a maximum pressure drop had been reached.

Oechsle, *Gottkehaskamp* and *Baur* reported at the beginning of the 1990s about a patented procedure for fine or sterile filtration of beer [66, 20, 67]. The aim of the development was a technology with easier automation compared to the approved pulp filtration in a horizontal kettle filter with a similar filtration principle. They used a filter aid mixture of granular highly calcined ceramic powder (containing alpha aluminium oxides) with fibres of cellulose and poly-ethylene, both partially fibrillated. The filter aid could remain in the filter for several filter cycles. In this case, it was regenerated in situ. For improvement, it was possible to remove and re-pre-coat the cakes. The authors observed that the caustic treatment regenerates the zeta potential of the cellulose.

Some articles have dealt with filtration using mixtures of cellulose fibres and starch. *Willmar* used potato starch [68]. *Eiselt et al.* presented in 1999 experiment results, which also had been achieved using cellulose and potato starch in pilot plant scale and large-scale filters [69]. These filter aids were not intended for regenerating. The starch should only lower the expenses by its lower price compared to those of other filter aids. 2003 *Blümel-huber et al.* reported about filtration experiments with three filter aids; a pure mixture of cellulose fibres, a mixture of cellulose, insoluble cornstarch and silica gel, as well as a pure silica gel [9].

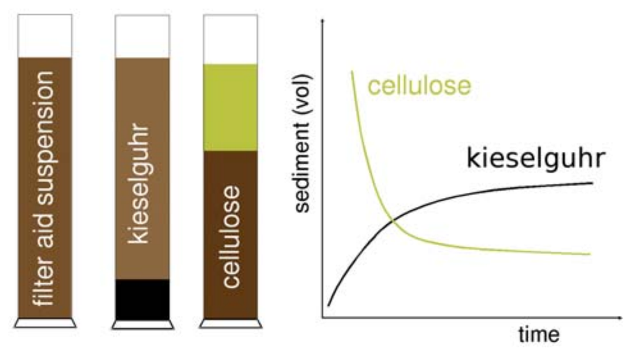

Fig. 2 Sedimentation behaviour of cellulose suspension [49]

5.2 Pre-coating Behaviour of Cellulose

As pre-coat, cellulose forms a paper-like sheet, which is fine-fibrous and grid-like, thus providing a good adhesion of the cakes while having non-clogging pores. Additionally, it is also able to bridge damaged places of the filter medium. It forms elastic, flexible filter cakes, which can be removed easily and cleanly from the supporting sheet. Cellulose is easily pre-coatable due to its specific weight compared to water. This works in candle filters as well [6, 70]. A hot pre-coating can result in irregular cakes [62], this is, however, controllable [49]. The sedimentation of cellulose differs from that of kieselguhr. While a kieselguhr suspension forms a rather firm deposit, which grows over time, a cellulose suspension quickly forms a sharp dividing line between rather clear liquid and loose deposit, which settles over time. Hence, any segregation must be carefully avoided [63].

To achieve even distribution, the pre-coating in horizontal filters must be carried out by a combined inlet into the filter from the top and from the bottom and at double velocity. A pre-coat of 1.75–2.0 kg/m² turned out optimum. Less pre-coat leads to early clogging, more to early exhausting of the sludge space between the filter elements [49].

The body-feed rate must be greater than 150 g/hl. The restricted sludge space leads to an early termination of the filtration when using filters with the common 25 mm sieve distance [49].

5.3 Filter Aid Composition

Naturally, success with this kind of beer filtration is dependent upon the properties of the cellulose fibres in use [63]. Simply stated, finer milling and a higher degree of fibrillation lead to an increase of flow resistance [64]. Additionally, three essential types of fibres are interacting. Long fibres form a supporting network, loosen up the cake, and raise its compressibility. The filter performance decreases with high proportions of long fibres as well as with very hazy beer. Short fibres form a fine net and thereby reduce the compressibility. Present in high proportions, also when filtering very hazy beer, they decrease the performance. Fibrillated fibres reduce the haze when used in suitable proportion, but they also increase the compressibility. In the interest of a moderate increase of pressure drop for the primary filtration, the fibril share should be between 2 and 4 % [49]. Fibrillated cellulose is indispensable. Not the refinement of the cellulose, but the degree of the mechanical pulping of the fibrils is decisive for the haze reduction effect and for the resulting brightness of the beer [62]. The big rough surface has a high retaining capacity for solids and colloids [6].

5.4 Specific Features of the Filter Aids

In the beginning of a filtration run, pressure increases nearly linearly. Filtrations of beer without previous separation, particularly beers of low filterability, lead to early termination of filtration. The thicker the filter cake is, the more susceptible it is to pressure shocks. Filtrations on two powder filters arranged one after the other (tandem filtrations) run successfully even without a separator [49, 60]. Higher body-feed at first, reduced after two hours, does not lead to the supposed improvement of the clarification and reduces the run time. Thicker pre-coating also reduces run time [61, 10].

The effect of an adsorbent can be improved by extending contact time [71]. A static mixer, which is arranged prior to the filter, improves the distribution and thereby the effect of the adsorptive elements of these depth-effective filter aids [62, 72]. When using PVPP-containing mixtures, a slightly lower haze of the filtrate can be achieved [61, 10].

Filter cakes made from cellulose fibres are inhomogeneous and compressible. The flow resistance increases with rising pressure drop in an over-proportionate manner. The filter equation $t = a_1{*}V^2 + a_0{*}V$ can be applied on cellulose-based filter aids [73, 64, 62]. Cellulose suspensions show a non-Newtonian flow be-haviour with light thixotropy [49]. Viscosity curves of such fluids with rising shear rate slope lie above those with descending shear rate slope [74]. As a result, there is an increased power demand for agitation of the suspension. Because of the tendency of the fibrils to get lumpy, axial flow impellers working according to the stator-rotor-principle are to be preferred to conventional rod agitators. They also allow an improved protection from oxygen up-take by blowing in carbon dioxide and by the avoidance of rotation of the liquor. The higher the cellulose concentration in a suspension is, the more slowly it settles. The water flow rate declines during the first filtrations with a new filter aid, afterwards remaining constant during further filtration-regeneration-cycles. The addition of ions or tap water leads to a higher water flow rate. The water flow rate is helpful to observe the composition of the filter aid mixture but not correlating with its filtration properties [49]. Also for other kinds of filter aids like kieselguhr, such a correlation is restrictedly valid at best [75].

Available highly pure alpha-celluloses are up to 3–10 % soluble in dilute caustic. Therefore, they must be "activated" by dilute caustic before their first filtration run. In the course of this, the losses amount to 5–7 %. Suspending fibrils is not as easily done as suspending cellulose flour. This has to be considered especially for the first mixing, but also for the substitution of the losses. The particle dimensions remain nearly unchanged for more than 20 filtration runs. Cellulose filter aid mixtures can be stored in a preservative solution without quality loss for more than a year. For short storage – up to five days – preservation can be omitted [49]. Filter aids on cellulose (and also cornstarch) basis are – material-appropriate storage assumed – not damageable by beer spoiling micro-organisms [9]. Cellulose causes no equipment abrasion [6].

Cellulose fibres in filtrates can be revealed microscopically. Due to their high autofluorescence, they can be easily identified using fluorescence microscopy. They also can be detected by their ability to rotate the plane of polarised light [76].

Cellulose can be composted ecologically, it can be fed to cattle, or it can be burnt [6]. The sludge capacity of common powder filters has to be enlarged for the pre-coat filtration by means of cellulose fibres [63].

5.5 Regeneration of Filter Aids on Cellulose Basis

Regeneration of Filter Aids

As far as the regeneration of filter aids is concerned, from the technological point of view, there are two primary aspects to consider. First, there is the mixing of pre-coat and body-feed filter aids. Second, there are changes in filter aid quality by abrasion and breaking of particles. From an economic point of view, the material loss and the expenditure for regeneration must also be taken into account [78]. A regenerable filter aid has to be stable and insoluble in the regeneration agents. Dilute caustic and dilute acids are normally used. Also, it must be sterilisable and should not be altered in its properties by the inevitable mechanical strain. Further, after regeneration, the filter aid must not bleed matter into the product. When using different filter aid compositions for pre-coat and body-feed, it must be possible to separate the total mixture into the original filter aids or it has to provide good properties to be used for consequent filter runs. The regeneration loss has to be controllable [49].

The regeneration of filter aids has to fulfil the following requirements. The changes on the particle surfaces have to be reversed, possible protein stabilisers have to be dissolved, yeast cells, proteins, other micro-organisms and beer constituents have to be removed [61].

Regeneration of Cellulose based Filter Aids

Evers regenerated cellulose by means of dilute caustic [49]. Temperature, time, and concentration of the regeneration agents are important parameters of the regeneration. He achieved the best results with a 30-minute regeneration by caustic with a concentration of two percent and a temperature between 40 and 50 °C. For stabilisation with silica gel he used the same process at 60 °C. As expected, the regeneration process had an influence on the fibre size distribution. Evers explained his results: at lower temperatures, proteins and gums cannot be washed out sufficiently. Higher temperatures as well as higher caustic concentrations and longer process times cause a coagulation of proteins. Thus, these cannot be washed out any more.

Regeneration can be done in the filter vessel. Sometimes, cold filter cakes are too compact to be removed by centrifugal effect [61, 10]. At warm temperatures, the regeneration process takes less time [63].

5.6 Comparison to Kieselguhr [49, 60, 62, 64]

Parallels: existing horizontal filter equipment can be used for both systems. The working methods and the advantages of the horizontal filters are transferable, e.g. the possibility to interrupt the filtration. With good pre-clarification, the filtration results are comparable in quality.

Advantages: the filter aid is regenerable and pressure shocks can be buffered more easily due to the compressibility of the filter cake.

Disadvantages: cellulose filtration without previous separation is very problematic. Flow rates can heavily decrease during filtration. The sludge space of common filters is too small.

Beer quality: the evaluated papers indicate that between cellulose and kieselguhr filtered beers, there is no difference in flavour or in analyses.

5.7 Economic Aspects

Filtration Criteria

Modern filters must be able to reduce haze in bottom fermented beer of 11 °Plato at a flow rate of 5 hl/m^2h from approx. 40 EBC-units to less than 0.8 EBC-units taken in both relevant angles, 90° and 25°, and should provide a normal filter run time of at least 10 hours. The run time of pre-coat filtration is shortened by a rise of the throughput because of the steeper rise of the pressure differential, which has to be considered for the process layout. None of the examined systems fulfil these criteria with cold-stored unfiltered beer of approx. 40 EBC-units.

Varying Mixtures for Pre-coat and Body-feed

The main media costs of kieselguhr filtration are for purchase and disposal of kieselguhr [77]. Highly pure alpha-cellulose costs four times as much as kieselguhr. Due to the similar filtration process, the comparison of the overall filtration costs can be reduced to the total media and labour costs including those for the regeneration. Today, about 8 to 16 filtration-regeneration-cycles are necessary to have comparable costs, depending on filtration process and cost situation.

Because of the economic necessity to regenerate the filter aid, it is virtually impossible to use different filter aid mixtures for pre-coat and body-feed. When removed from the filter vessel, the pre-coat and the body-feed fractions are mixed up. The resulting mixture would otherwise have to provide useful properties for the following filtrations or to be separated again, either before or after regeneration.

Either a good pre-clarification or a tandem-filtration is necessary to attain the common target brightness of the beer by cellulose filtration. Today's known systems require existing equipment to work economically. Thus, these systems cannot be considered marketable alternatives for most of the breweries.

6 Starting Points for more Developments

Beer production

Making beer bright and stable through the removal of unwanted haze is the aim of the filtration. The entire beer production must be taken into account. After all, the turbidity load reaching the filter and the beer filterability depend upon the whole technology [79, 80, 81, 82] and upon the equipment [83, 84], starting at the barley field [85]. Brewhouse process [81] und storage [86] have an important influence. Subsequent to a cold storage of at least one week, beer hardly contains any yeast cells or other particles of 6 µm diameter and larger. The main part of the particles to be separated range in size from 0.4 to 4 µm and is composed pre-dominantly of proteins. The colloids, which are separated during the stabilisation process, are not being strained but are rather removed by adsorption [87].

The whole brewing process comprises a series of solid/liquid separations: lautering, hot break removal, cold break removal, yeast crop, deposits removal, filtration and stabilisation. Filtration can virtually be affected by every upstream separation step. Every single sub-process can be considered a preparation for a successful filtration in regard of avoiding unfavourable constituents, which can result in filtration problems, as well as provide an opportunity for early separation of haze particles [25, 88].

No brewery will change nor question the methods of their whole production just to be able to invent a new filtration technology. Therefore, simple and economically attainable methods must be found. Filtration can be benefited for example by dosing silica sol into the storage tank. By a dosing just upstream of the filtration, the latter can be sharpened with respect to its separation effect [89, 90, 91]. Beer filtration with cellulose might become feasible through technological changes with regard to beer storage.

Modified Cellulose Fibres

With respect to the adsorption of particles to be separated from beer, the negative zeta potential of unmodified cellulose is disadvantageous. The quantification of the magnitude of the electro-kinetic potential at the double layer between solid and liquid is called zeta potential [92]. Shearing a part of this double layer surrounding charged particles in polar dispersions is transporting net charge. During this shearing, there is an electric potential in the slipping plane between the stationary layer attached to the particle and the dispersion medium, the zeta potential [93, 94]. The higher the pH, the greater the reduction in zeta potential [95]. The effect of unmodified cellulose is similar to that of a weak cation exchanger [96]. In aqueous dispersions, the haze-forming constituents of beer and other organic particles are negatively charged. Thus, no adsorption is to be expected. By electric adhesion, a positively charged surface of an adsorbent brings forward the transport of particles to the adsorbent as well as the adherence. This effect is called polar adsorption [94].

There are ways to change the electro-kinetic charge of cellulose from negative to positive. Processes like direct cationisation or cationisation by radical grafting are used. Also, mechanically treated cellulose can be changed by food safe resins of polyamine/epichlorhydrine or melamine/formaldehyde [97, 98]. Through this, the adsorption capacity of cellulose for negatively charged matter can be multiplied. *Matzmorr* and *Werner* proved this using potential measuring in flowing medium [94]. The adsorption capacity of modified celluloses depends on the degree of shearing and on the conductivity of the liquor [99]. Such products were developed in the 1980s to replace asbestos, partly in combination with kieselguhr and perlite. These products have not been designed for regeneration [100]. For more than 25 years, fibrillated products with a positive zeta potential and accordingly positive adsorption properties have been available for filter sheets [101]. Regenerable zeta potential is already being used for membrane filtrations [102]. Something similar might be developed for the pre-coat filtration by cellulose-based filter aids.

Additional Filter Aids

Kieselguhr filtration uses mostly additional filter aids, mainly perlite and cellulose as well as the clarification agents silica gel and PVPP. To influence the characteristics of the filtrations in regard to quality as well as quantity is the function of these adjuncts [103]. In the same manner, one could imagine to improve the properties of the filtration by filter aids on the basis of cellulose. The straining effect, the adsorptive effect and the run time maybe could be improved by adjuncts.

The following filter agents are known: active carbon can improve the separation effect of pre-coat filtrations by cellulose [104]. But beer quality is changed by the high adsorption rate of positive beer constituents. Due to the health-risk for workers, asbestos cannot be used any more, though it has best filtration properties [100]. Bentonite is not pre-coatable and not stable in chemical agents. Precipitated silica is not regenerable because it is soluble in hot acid and hot caustic [104]. Filtering charcoal is described in the literature as non-activated carbon for filtration purposes. It does not have any adsorptive effect. There is nothing known about any use in the brewing industry [105]. Silica gel is commonly used in the brewing industry as a protein stabilising agent, being added as an adjunct to the pre-coat filtration aids. In principle, with a fitting particle size distribution, it could be used as a filter aid [106]. This could be advantageous. Impurity as well as dependence on imports could be avoided by industrial production. Filter cakes could be less thick [87]. However, silica gel only partly endures caustic regeneration [49] and is easily being broken or abraded [76]. Kieselguhr is non-biodegradable and presents a health-risk. Man-made fibres were introduced in 2007 as main component of a regenerable filter aid on basis of synthetic polymers (PS and PVPP) [107]. The findings are not significant yet. Similar technologies have also been described by *Brocheton et al.* [108] in 1995 and *Bonacchelli et al.* [109] in the late 1990s. However, nothing is known about any use on commercial scale. Mineral fibres are non-biodegradable. PE floats and is hardly pre-coatable. Very good filtration results can be achieved by combinations of perlite and cellulose [110]. But perlite can hardly be sterilised and can easily be degraded by pumps, so can hardly be regenerated. Polyamide (Nylon 66) is non-biodegradable though it has a sta-bilising effect. As part of the F&S system, PVPP is well-studied but not biologically renewable [49]. (Corn) starch is partly soluble at 50 °C and higher. Thus, it cannot be regenerated or heat sterilised. Due to its ball-like and non-porous structure, it cannot improve the filtration properties of a filter aid [111]. Sintered glass cannot bear the inevitable mechanical stress [112].

Methodical Filtration Experiments

Making good progress seems possible by a thorough procurement market analysis and methodical experiments in analysing new cellulose mixtures and as the case may be other adjuncts. Also, there is a permanent increase in relevant knowledge as well as amelioration in fibre supply.

Prospect

Production methods, quality, availability, variation range and prices of cellulose fibres are being continuously improved. The possibility to use alternative filter aids such as cellulose is a must for newly-designed equipment [73].

7 Summary

Cellulose is a renewable and a completely biodegradable raw material. The following properties of the filter aids on basis of cellulose have to be considered for process design. It is easily pre-coatable, forming elastic, flexible filter cakes. These are also inhomogeneous and compressible. The sedimentation behaviour of cellulose differs from that of kieselguhr. Long, short and fibrillated fibres are mixed for feasible haze reduction effect and run time. Regenerating the filter aid is necessary for economic reason. The regeneration process can be done using dilute caustic. Filter aid suspensions can be stored in preservative solutions for long periods of time without quality loss.

Cellulose filtration requires a good pre-clarification and thus is very problematic without previous separation. The sludge space of common filters is too small. The previously compiled knowledge about the cellulose filtration does not yet allow economically feasible operation.

Cellulose fibres fulfil the demands on filter aids for the pre-coat filtration. There is no difference in flavour or in analyses between kieselguhr and cellulose filtered beers. If the procedural chain of the filtration can be designed comparable to that of the kieselguhrfiltration, the breweries can maintain their usual methods on existing equipment without expensive rebuilding and without fundamental changes. They also can easily cope with frequent batch changes.

8 References

1. Pöschl, M.; Zimmermann, U. and Geiger, E.: Historischer Überblick über die Bierfiltration und Bierstabilisierung. Der Weihenstephaner **75** (2007), pp. 117-121.

2. Hertel, M.: Abfallarme Klärfiltration in Brauereien. BIfA-Texte Nr. 12. BIfA, Augsburg, 1999, pp. 14-15.

3. Lyko, H.: Filter und Filtermittel zur Tiefenfiltration von Bier. F&S **22** (2008), pp. 196-198.

4. Eßlinger, H.M.: Filtration in der Brauerei. BRAUWELT **132** (1992), pp. 611-613.

5. Schmidt, O.: Mit Kieselgur oder Zellulose? Das Deutsche Weinmagazin **59** (2004), pp. 29-35.

6. Speckner, J. and Kieninger, H.: Cellulose als Filterhilfsmittel. BRAUWELT **124** (1984), pp. 2058-2066.

7. Ruß, W. and Meyer-Pittroff, R.: Rechtliche Vorschriften für Kieselgur. BRAUWELT **141** (2001), pp. 343-346.

8. International Agency for Research on Cancer [ed.]: IARC monographs on the evaluation of carcinogenic risks to humans. Vol. 68: Silica, Some Silicates, Coal Dust and para-Aramid Fibrils. IARC, Lyon, 1997, p. 211.

9. Blümelhuber, G.; Bleier, B. and Meyer-Pittroff, R.: Untersuchungen an einem alternativen Filterhilfsmittel auf Zellulosefaserbasis. BRAUWELT **143** (2003), pp. 244-246.

10. Donhauser, S.; Wagner, D. and Waubke, C.: Bierfiltration ohne Kieselgur. BRAUWELT **128** (1988), pp. 1938-1946.

11. Schleicher, T.: Flusskalzinierung von Kieselgur. WBC 2008, ref. Brauindustrie **93** (2008), p. 88.

12. Schleicher, T. and Ruß, W.: Einflüsse auf die Cristobalitbildung bei der Herstellung flusskalzinierter Kieselguren. Brauindustrie **93** (2008), pp. 30-33.

13. BioAbfV: Bioabfallverordnung from the 21st September 1998 (BGBl. I p. 2955), last amended by article 5 of the ordinance from the 20th October 2006 (BGBl. I p. 2298).

14. DüV: Düngeverordnung from the 10th January 2006 (BGBl. I p. 20).

15. Penschke, A.: Konservierung von Trebern und Kieselgurschlamm für einen Einsatz in Ziegeln und Kalksandstein. Dissertation, TU München, 1998, pp. 114-115.

16. Ruß, W.: Möglichkeiten zur Verwertung der Reststoffe Treber, Kieselgurschlamm und Altetiketten bei der Herstellung von Asphaltbeton und Ziegeln. Dissertation, TU München, 1995, pp. 156.

17. FuttMV: Futtermittelverordnung as amended on 24th May 2007 (BGBl. I p. 770), last amended by the ordinance from the 15th December 2008 (BGBl. I p. 2483).

18. AbfAblV: Abfallablagerungsverordnung from the 20th February 2001 (BGBl. I p. 305), last amended by article 1 of the ordinance from the 13th December 2006 (BGBl. I p. 2860).

19. Blümelhuber, G.: Kieselgurschlämme? Entsorgungsprobleme? BRAUWELT **147** (2007), pp. 757-760.

20. Oechsle, D.; Gottkehaskamp, L. and Baur, W.: New Procedure for Fine-Sterile Filtration by Means of Regenerable Filter Agents in the Primus-Filter (RFM-Process). MBAA Technical Quaterly **29** (1992), pp. 101-105.

21. Schmid, N. et al.: Praxisergebnisse mit der Befis-Technologie. BRAUWELT **145** (2005), pp. 747-754.

22. Schmid, N.: Verbesserung der filtrationstechnischen Eigenschaften von Filterhilfsmitteln durch ein thermisches Verfahren. Dissertation, TU München, 2002, pp. 165-167.

23. Höhn, G.: Neue Wege im Recycling von Kieselgur. BRAUWELT **139** (1999), p. 992.

24. Maiwald, R. et al.: Neues Verfahren zur thermischen Regenerierung von Kieselgur. BRAUWELT **139** (1999), pp. 2044-2051.

25. Boulton, C. and Quain, D.: Making Choices. Brewer's Guardian **137** (2008), pp. 24-28.

26. Selig, R.: Quer zum Strom. Brauindustrie **93** (2008), pp. 36-37.

27. Freeman, G.: The move to crossflow. Brewer's Guardian **136** (2007), pp. 46-50.

28. Fengel, D. and Wegener, G.: Wood – Chemistry, Ultrastructure, Reactions. Walter de Gruyter, Berlin, 1989, pp. 39-43, 66-67.

29. Heldt, H.-W. and Picchulla, B.: Pflanzenbiochemie. 4. Auflage. Spektrum, Heidelberg, 2008, p. 258.

30. Gerhartz, W. [ed.]: Ullmann's encyclopedia of industrial chemistry. VCH, Weinheim, 1986, pp. 383-387.

31. Hums, N.: Allgemeine Grundlagen der Filtration mit Filterhilfsmitteln. Brauerei Journal **98** (1981), pp. 343-348.

32. Yasar, S.: Beurteilung der technologischen Qualität von Cellulose, Hemizellulosen und Lignin bei Miscanthus ‚Giganteus' und Cannabis sativa L. Dissertation, Universität Wien, 1999, pp. 100-109.

33. Meyer, M. and Witte, A.: Produktschonung versus Wirtschaftlichkeit? BRAUWELT **148** (2008), pp. 1345-1348.

34. Steffens, V.: Aus Holz wird Papier. Electronic resource, coTec, Rosenheim, 2002.

35. Braun, M.; Teichert, O. and Zweck, A.: Übersichtsstudie Biokatalyse in der industriellen Produktion. Fakten zur weißen Biotechnologie. VDI, Düsseldorf, 2007, p. 43.

36. Gasper, H.: Filtersysteme zur Klärfiltration. BRAUWELT **132** (1992), pp. 1763-1768.

37. Stieß, M.: Mechanische Verfahrenstechnik 2. Springer, Berlin, 1994, pp. 97-99.

38. Luckert, K. [ed.]: Handbuch der mechanischen Fest-Flüssig-Trennung. Vulkan, Essen, 2004, p. 145.

39. Husemann, K.; Hebmüller, F. and Eßlinger, M.: Bedeutung der Tiefenfiltration bei der Kieselgurfiltration von Bier (1). Monatsschrift für Brauwissenschaft **55** (2002), pp. 46-50.

40. Gupte, A.R.: Experimentelle Untersuchung der Einflüsse von Porosität und Korngrößenverteilung im Widerstandsgesetz der Porenströmung. Dissertation, Universität Karlsruhe, 1970, p. 86.

41. Hebmüller, F.: Einflussfaktoren auf die Kieselgurfiltration von Bier. Dissertation, TU Bergakademie Freiberg, 2003, p. 96.

42. Raistrick, J.H.: Advantages of Adsorptive Filtration. Filtration & Separation **23** (1986), pp. 354-357.

43. Kaltner, D.: Untersuchungen zur Ausbildung des Hopfenaromas und technologische Maßnahmen zur Erzeugung hopfenaromatischer Biere. Dissertation, TU München, 2000, p. 12.

44. Ruß, W.; Schmid, N. and Meyer-Pittroff, R.: Thermische Behandlung von Kieselguren zur Verbesserung der filtrationstechnischen Eigenschaften und zum Recycling von Kieselgurschlamm. Monatsschrift für Brauwissenschaft **56** (2003), pp. 134-140.

45. Lindemann, B.; Fontaine, J. and Krüger, E.: Der Einfluß filtrationshemmender Stoffe auf die Vorhersage der Filtrierbarkeit des Bieres. Teil 1: Einflußfaktoren auf das Ergebnis des Membranfiltertests nach Esser. Monatsschrift für Brauwissenschaft **44** (1991), pp. 336-340.

46. Lindemann, B.; Fontaine, J. and Krüger, E.: Der Einfluß filtrationshemmender Stoffe auf die Vorhersage der Filtrierbarkeit des Bieres. Teil 2: Einflußfaktoren auf das Ergebnis des Kieselgurfiltertests nach Raible. Monatsschrift für Brauwissenschaft **44** (1991), pp. 377-382.

47. Wagner, N.: β-Glucan in Bier und Bedeutung dieser Stoffgruppe für die Bierfiltration. Dissertation, TU Berlin, 1990, p. 177.

48. Heertjes, P.M. and Zuideveld, P.: Clarification of Liquids using filter aids. Powder Technology **19** (1978), pp. 17-30.

49. Evers, H.: Ersatz der Kieselgur bei der Bierfiltration durch ein regenerierbares Filterhilfsmittel. Dissertation, TU Berlin, 1996.

50. Eisenring, R.: Untersuchung der Filtrierbarkeit und kolloidalen Stabilität von Bier und anderen Getränken. Dissertation, ETH Zürich, 1995, pp. 103-104.

51. Svarovsky, L.: Solid-Liquid-Separation. Fourth Edition. Butterworth-Heinemann, Oxford, 2000, pp. 305-131.

52. Dreier, W.: Beitrag zur Kenntnis der Filtrationsvorgänge. Dissertation, ETH Zürich, 1957, pp. 56-92.

53. Narziß, L. and Eßlinger, H.M.: Einflußfaktoren auf die Filtrierbarkeit des Bieres, Teil 1: Filtrationstheorie. Monatsschrift für Brauwissenschaft **39** (1986), pp. 424-427.

54. Lindemann, B.: Bewertung der Kieselgurfiltration von Bier. Dissertation, TU Berlin, 1992, p. 123.

55. Drost, M.A. and Windhab, E.J.: Nicht newton‘sches Fließverhalten von Bier beim Durchströmen von porösen Medien als mögliche Erklärung für einen plötzlichen Anstieg der Druckdifferenz bei der Kieselgurfiltration. Monatsschrift für Brauwissenschaft **54** (2001), pp. 44-47.

56. Evers, H.: Entwicklung der kieselgurfreien Filtration. BRAUWELT **144** (2004), pp. 1700-1704.

57. Enzinger-Werke AG [ed.]: Fabrikation von Filtermasse. Enzinger Nachrichten 1951, pp. 9-14.

58. De Clerck, J.: Die neuen Verfahren zum Klären von Bier. Monatsschrift für Brauwissenschaft 3 (1950), pp. 1-7.

59. Beckett, M.H.: Sterile PuIp Filtration Implementation and Optimization at the Adolph Coors Company. MBAA Technical Quarterly **22** (1985), pp. 53-55.

60. Zeller, A. et al.: New Filter System for Kieselguhr-Free Filtration of Beer – Concept and Practical Results. Lecture on WFC **10** (2008).

61. Donhauser, S.; Wagner, D. and Walla, G.: Praktische Erfahrungen mit modernen Filtersystemen. BRAUWELT **128** (1988), pp. 108-116.

62. Wackerbauer, K. and Gaub, R.: F&S Filtration in der praktischen Erprobung. BRAUWELT **129** (1989), pp. 1680-1689.

63. Wackerbauer, K. and Evers, H.: Kieselguhr-free filtration by means of the F&S System. BRAUWELT International **11** (1993), pp. 128-132.

64. Liu, Z.: Untersuchungen über das Verhalten zellulosehaltiger Filterhilfsmittel für den Einsatz bei der Bierfiltration. Dissertation, TU Berlin, 1997.

65. Grund, H.; Neukirchner, G. and Becker, H.: Entkeimungsfiltration mit regenerierbarem Filterhilfsmittel. BRAUWELT **130** (1990), pp. 2164-2168.

66. Oechsle, D.; Gottkehaskamp, L. and Baur, W.: Advances in Automated Sterile Filtration with Regenerable Filter Aids. Brewer’s Guardian **122** (1993), pp. 20-23.

67. Oechsle, D. et al.: Automatisierte Sterilfiltration mit regenerierbaren Filterhilfsmitteln. Brauindustrie **78** (1993), pp. 102-106.

68. Willmar, H.: Einsatz von Stärke und Zellstoff. BRAUWELT **125** (1985), pp. 126-129.

69. Eiselt, G.; Back, W. and Gerdes, E.: Anschwemmfiltration mit organischen Filterhilfsmitteln: Erfahrungen im Technikumsmaßstab und im großtechnischen Einsatz. Proceedings of the 27th EBC Congress (1999), pp. 797-806, Hans Carl, Nürnberg.

70. Kain, J.: Entwicklung und Verfahrenstechnik eines Kerzenfiltersystems (Twin-Flow-System) als Anschwemmfilter. Dissertation, TU München, 2005, pp. 64, 142.

71. Weyh, H.: Wirkung und Nebenwirkungen von Bierklärmitteln unter besonderer Berücksichtigung von Polyvinylpolypyrrolidon (PVPP). Monatsschrift für Brauwissenschaft **32** (1979), pp. 69-73.

72. Hums, N.: Wissenschaftliche Grundlagen und Stand der Technik des Bierstabilisierungsverfahrens mit PVPP im Recycling. Monatsschrift für Brauerei **34** (1981), pp. 83-85.

73. Alles, C.: Prozeßstrategien für die Filtration mit kompressiblen Kuchen. Dissertation, TH Karlsruhe, 2000, p. 164.

74. Linemann, A.: Untersuchungen der Struktureigenschafts-Beziehungen von Beta-Glucan bei der Bierherstellung. Dissertation, TU Berlin, 1995, pp. 7-8.

75. Falk, H. and Sommer, K.: Optimierung von Filtermitteln. Proceedings of the 22th EBC Congress (1989), pp. 401-412, Hans Carl, Nürnberg.

76. Hartmann, K.: Bedeutung rohstoffbedingter Inhaltsstoffe und produktionstechnologischer Einflüsse auf die Trübungsproblematik im Bier. Dissertation, TU München, 2006, pp. 97, 102-104.

77. Baur, G.: Quantitative und qualitative Evaluierung und Optimierung der Medienströme bei Praxis-Systemen und -Verfahren zur Bierfiltration und kolloidalen Stabilisierung. Dissertation, TU München, 2003, p. 110.

78. Hackl et al.: Filterhilfsmittelfiltration. Fortschrittsberichte VDI; Reihe 3: Verfahrenstechnik Nr. 348. VDI Verlag, Düsseldorf, 1993, p. 162.

79. Kreisz, S.: Der Einfluss von Polysacchariden aus Malz, Hefe und Bakterien auf die Filtrierbarkeit von Würze und Bier. Dissertation, TU München, 2003, pp. 112-114.

80. Esser, K.D. and Schildbach, R.: Untersuchungen zur Vorhersage der Filtrierbarkeit des Bieres. Monatsschrift für Brauerei **25** (1972), pp. 280-285.

81. Schur, F.: Bierfiltration und Einflüsse auf die Bierfiltrierbarkeit. Proceedings of the 22th EBC Congress (1999), pp. 371-383, Hans Carl, Nürnberg.

82. Schütz et al.: Analytische Kontrollmöglichkeiten zur Optimierung technologischer Prozesse. BRAUWELT **146** (2006), pp. 312-316.

83. Drost, M.A.: Methoden zur Untersuchung der Auswirkungen mechanischer Belastung auf kolloidale Struktur, Rheologie und Filtrationsverhalten von Bier. Dissertation, ETH Zürich, 1999, pp. 140-144.

84. Eßlinger, H.M.: Einflußfaktoren auf die Filtrierbarkeit des Bieres. Dissertation, TU München, 1985, pp. 110-111.

85. Eiselt, G.: Untersuchungen über hochmolekulares Beta-Glucan. Dissertation, TU Berlin, 1995, pp. 119-121.

86. Eberhard, M.: Optimisation of Filtration by Application of Data Mining Methods. Dissertation, TU München, 2006, p. 102.

87. Reed, R.J.R.: Centenary Review Article – Beer Filtration. Journal of the lnstitute of Brewing **92** (1986), pp. 413-419.

88. Annemüller, G.: Über die Filtrierbarkeit des Bieres – Beurteilung und Einfluß der Inhaltsstoffe. Monatsschrift für Brauwissenschaft **44** (1991), pp. 64-71.

89. Raible, K. et al.: Kieselsäuresol – ein Bierstabilisierungsmittel zur Verbesserung der Filtrationseigenschaften von Bier. Monatsschrift für Brauwissenschaft **36** (1983), pp. 76-82.

90. Raible, K.; Heinrich, T. and Niemsch, K.: Eine einfache, neue Methode zur Bewertung der Filtrationseigenschaften von Bier. Monatsschrift für Brauwissenschaft **43** (1990), pp. 60-65.

91. Schnick, T.: Untersuchung zur Klärwirkung modifizierter Kieselsole und Kieselsolgemische am Beispiel einer Modelltrübungssuspension. Dissertation, TU Berlin, 2003, p. 95.

92. Gasper, H. [ed.]; Oechsle, D. [ed.] and Pongratz, E. [ed.]: Handbuch der industriellen Fest/Flüssig-Filtration. Wiley-VCH, Weinheim, 2000, pp. 23-24.

93. Bijsterbosch, B.H.: Zur Stabilität von Kolloiden in wäßrigen Systemen. Die Rolle des Zetapotentials und der Einfluß adsorbierter Polymere. Zeitschrift für Wasser- und Abwasser-Forschung **16** (1983), pp. 125-131.

94. Matzmorr, W. and Werner, U.: Verbesserung des Filtrationsvermögens von Filterschichten durch Modifizierung der Oberflächenladung. Chemie-lngenieur-Technik **58** (1986), pp. 230-231.

95. Oechsle, D. and Brenner, F.: Die Schichtenfiltration. Getränketechnik **4** (1988) pp. 232-247.

96. Kräuter, A.: Sorption organischer Wasserschadstoffe an abgestorbene pflanzliche Biomasse. Dissertation, Universität Fridericiana Karlsruhe, 2001, p. 117.

97. Gruber E. et al.: Untersuchung der Synthesebedingungen und der Eigenschaften von kationisierten Zellstoffen und ihrer Einsatzmöglichkeiten als umweltfreundliche Papierhilfsmittel. Abschlussbericht über das AiF-Projekt Nr. 10210, TU Darmstadt, 1998, pp. 9-39.

98. Gruber, E.; Pätzold, R. and Gattermayer, J.: Entwicklung von modifizierten Zellstoffen und Stärken zur Entfernung von Störstoffen

aus Papier-Fabrikationswässern bzw. zur Fixierung im Papier. Abschlussbericht über das AiF-Projekt Nr. 11421N, TU Darmstadt, 2000, pp. 31-38.

99. Gattermayer, J.: Darstellung von kationischen Zellstoffen und Untersuchung der Wirkungsmechanismen bei ihrem Einsatz in der Papierherstellung. Dissertation, TU Darmstadt, 2001, pp. 149-150.

100. Tesch, H.: Asbestersatz – Filterflocken mit positivem elektrokinetischem (Zeta)Filtrationspotential. Brauindustrie **73** (1988), pp. 540-542.

101. Raistrick, J.H.: The Relevance of Zeta Potential to the Filtration of Small Particles from Potable Liquids. Filtration & Separation **20** (1983), pp. 124-126.

102. Krottenthaler et al.: Sterile filtration of beer by membranes - economical and physiological aspects. Proceedings of the 29th EBC Congress (2003), electronic resource, no. 28, Hans Carl, Nürnberg.

103. Fischer et al.: Die Kieselgur – wichtigstes Filterhilfsmittel der Anschwemmfiltration in Kombination mit anderen Filterhilfs- und Klärmitteln. BRAUWELT **137** (1997), pp. 2056-2059.

104. Fütterer, R.: Filterhilfsmittel – Wirkungsweise, spezifische Eigenschaften und Möglichkeiten zur Qualitätskontrolle, Teil II. Chemische Technik **29** (1977), pp. 18-24.

105. Moll, M.: Les adjuvants et supports de filtration de la bière. Bios **5** (1974), pp. 101-110.

106. Clark, B.E.; Crabb, D.; Lovell, A.L. and Smith, C. (1980) ref. Reed, R.J.R.: Centenary Review Article – Beer Filtration. Journal of the lnstitute of Brewing **92** (1986), pp. 413-419.

107. Pfaller, B.: 15. Deutscher Brauertag – Branche diskutierte Trends. Brauerei Forum **23** (2008), pp. 6-9.

108. Brocheton et al.: Principes d‘un nouveau procédé de filtration de la bière. Proceedings of the 25th EBC Congress (1995), pp. 427-436, Hans Carl, Nürnberg.

109. Bonacchelli, B.; Harmegnies, F. and Tigel, R.: Bierfiltration mit regenerierbaren Filterhilfsmitteln: halbindustrielle Ergebnisse. Proceedings of the 27th EBC Congress (1999), pp. 807-814, Hans Carl, Nürnberg.

110. Geiger, E.; Wagner, D. and Lipps, M.: Perlite als Alternative zur Kieselgur bei der Bierfiltration. Der Weihenstephaner **68** (2001), pp. 159-161.

111. Brenner, F. and Oechsle, D.: Tendenzen in der Bierfiltration. BRAUWELT **127** (1987), p. 118-125.

112. Ludwig, A.: Zur Verbesserung der Langzeitstabilität von Verfahren mit immobilisierter Hefe bei der Hauptgärung. Dissertation, TU Berlin, 2003, pp. 43-44.

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