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Continuous Beer Production

Mark Strobl

Abstract

Although the barley and hop harvest is a batch process, the ingredients are storable to a certain extent, so malting and brewing can be performed continuously. The more expensive machinery and energy are becoming, the more continuous production is becoming efficient. The advantages are smaller capacities, less energy consumption and more recuperation. Most filling processes run semi continuously, and energy-consuming processes like malting can also run continuously around the clock. Disadvantages are necessary buffers, microbiological contamination and less flexibility in producing different types of beer or adjusting the production to seasonal fluctuations. Mistakes and errors increase, even if accuracy and in-line sensors help to keep quality stable for some time. This article discusses benefits and limits of continuous technology.

Keywords: continuous process, malting, brewing, fermentation, filtration, bottling, error progress, multisensor behaviour

1. History of continuous beer production

The wish to feel good is the wish to feel good continuously. Transferring this to the consumption of beer may lead to the wish to produce beer continuously (**Table 1**).

During the last 100 years, more and more continuous steps have been integrated into the brewing process. Lots of energy can be saved during malting and wort boiling. Filling of the beer needs lots of expensive and labour-intensive machines, which work efficiently, if pursued in a continuous manner.

Brewing processes are mainly mixing and clarification processes. During malting, mashing, wort boiling and fermentation, mixing can easily be performed in a continuous manner. Clarification and separation processes like lautering, wort clarification, yeast settling and maturation are traditionally performed by gravity and settling in a batch process. For the continuous process, these have to be altered into separation processes by decanters, centrifuges and crossflow filtrations. The intersection between a batch process and a continuous process needs buffer vats, tanks before and after the continuous process. Buffers are capacities that cost money, space and energy, have to be cleaned and maintained and limit the advantages of a pure continuous process. In bottling lines conveyer buffers need space before and after each machine, which cost a lot of money and need to be controlled by computers that link the aggregates.

Steps in beer production			
Process	Aims	Batch	Continuous
Steeping	Mixing	Steep tank	Screw conveyers
Germination	Mixing	Malting box, tower malting	Worm conveyers
Kilning	Mixing	Floor kiln	Air conveyers
Milling	Mixing		All mills
Mashing	Mixing	Mash tun	Tube heat exchanger
Lautering	Separation	Lauter tun, mash filter	Centrifuge, decanter, Nessie
Wort boiling	Mixing	Copper	Heat exchanger
Wort clarification	Separation	Whirlpool, flotation	Decanter, centrifuge
Wort aeration	Mixing	Flotation	Inline nozzle
Fermentation	Mixing	Fermentation tub or tank	Immobilised yeast
Maturation	Separation	Storage tank	Centrifuge
Filtration	Separation	Dead-end cave filtration	Crossflow filter
Filling	Avoiding contaminations and oxygen	Tank lorries, kegs, stationary fillers	Rotary-type machines for kegs and bottles

Table 1.
Main processes in beer making, their aims and the batchwise and continuous machines.

2. Pros and cons of continuous production versus batch process

Continuous process advantages	Batch process: advantages
• Less volume, limited space requirements [1]	• Are easier to control
• Less energy and water consumption	• Are easier to change, if other beer varieties are needed
• Reduced peak consumption of utilities [1]	• Quantity demands can be respected
• Reduced extract losses [1]	• Containers are better and more often to be cleaned
• Reduced waste disposal [1]	• Processes are less automatised and complicated
• Higher yields	• Machinery has less moving parts and less ware parts
• Higher degree of automatisation	• If things go wrong, it means less stress for the brewers (and yeasts)

Table 2.
Continuous brewing processes versus batch processes—the advantages.

3. Continuous malting

As malting needs lots of water and energy and only a few malts are produced in big amounts, continuous or semi continuous production is used more often than in brewing (**Table 2**). This means steeping, germination and kilning during the continuous transportation of the grains [3].

In 1960 the Domalt system was built in Toronto (Toronto malting). Barley was transported by water with a pump into a slope malt conditioning screw. The barley is slowly transported upward against rinsing water. Then the barley fell onto an endless filter belt [4]. Water was sprayed on the barley and aerated, and the degree of steeping was adjusted. It fell on a conveyer situated below for the germination. The belt is moved

at 0.7 m/h, the green malt being 0.9 m high. Stationary turning machines homogenised the germinating grains. Withering and kilning were also conducted on conveyers by tempered air blowing through the debris. Finally the malt was cooled down by air. Only one person controlled the process. Yields were 1–1.5% above per batch systems. Energy and water were saved [3]. Production size was 11,600 t/a. The steeping and germination time was 100–110 h for two rowed and 70–80 h with multi-rowed barley [4]. Advantages were the quick pregermination at less moisture, the better cytolysis, the shorter time, a bigger kernel volume after the kilning [4], less work labour, better automatisisation and less water consumption at higher investment costs.

A Soviet system called Bartnew worked with rotating slanted 1–2° slope long drums. The grains moved 20–60 mm per turn of the drum. In the end the grain had passed every germination stage and was kilned in a vertical kiln with conical chutes [3].

The process could be regulated, 40–70 h for the steeping, 70–200 h for germination and 6–20 h for the kilning [3]. The German Democratic Republic (GDR) continuous malting needed a total of 73–105 h, producing 10,000 t/a. The water was reused for steeping with an addition of 0.2% caustic soda [3].

Moving pile systems by Ostertag, Seeger and Lausmann were turning and moving the malt under spraying or aeration with tempered air. Today tower malting is a semi continuous malt production. The steps on the floors take 9–24 h [4]. The batches are synchronised to the lorry sizes which fetch the malt to the breweries, the production speed is in a weekly rhythm, the silos buffer the amount of the barley harvest, and the demand of malt is by the annual variability of beer production.

4. Continuous brewhouse

The important utilities consumed in the brewhouse are malt grist, hot water for mashing and lautering, steam and water as a cooling liquid. In a batch brewhouse, different batches are processed at the same time and consequently lead to crucial electricity, steam and water consumption peaks.

Milling: usually milling is a continuous process, no matter if wet mill, roller or a hammer mill is used. The malt silo and the milling body are the buffers before and after the milling. Capacities can be reduced, if the mashing process is continuous and not needing the tons per brew in less than 20 min to assure equal treatment of the grains. The comminution degree is dependent on the lautering process following. If continuous the husks do not need to be maintained, like for lautering. This means more yield but less blank worts.

Mashing: infusion mashing is easily to be performed continuously. Plate or tube heat exchangers vary temperature and speed of the mash. Plate heat exchangers have limited applications for products with particles and/or fibres, while tube heat exchangers have the lower energy recovery rates [5]. Mash cannot run against mash like in a plate heat exchanger. An intermedia water circuit is necessary to recuperate energy in the casing pipe. Mixing while heating has to assure equality of the treatment as much as possible.

In 1998, Meura started the development of the continuous brewing concept. A complete pilot plant was installed in 1999. The first operation of the Meurabrew on an industrial scale of 200 hl/h wort (up to 20°P) took place in 2007. A similar order for a plant in Fuzhou, China, was obtained. The entire operation is managed by 45 people, with just 2 men per shift to run the brewing operation from raw material intake to filtered beer during the daytime [1].

Different mash vessels are keeping mash at constant temperature with a specific holding time. A continuous flow passes these vessels. Three parallel filters assure a regular continuous filtration process [1].

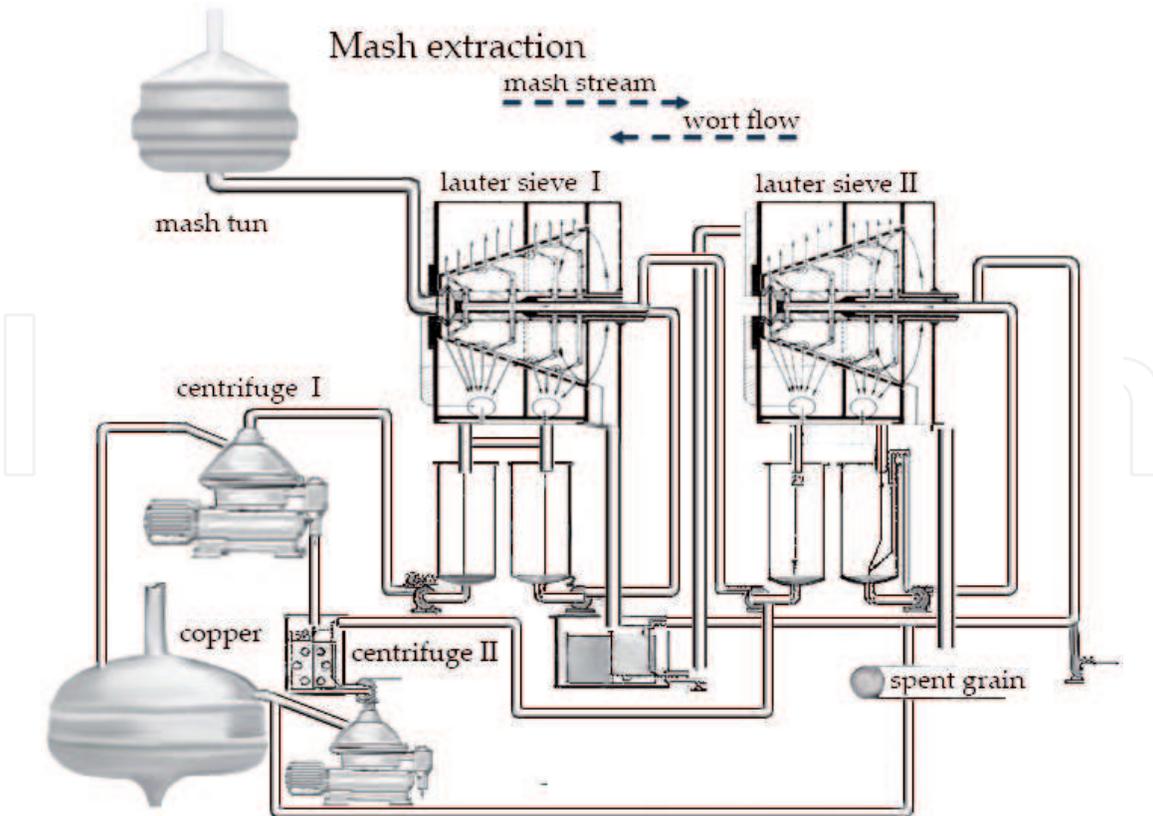


Figure 1.
The continuous step of lautering in a “Pablo Brewhouse” adaptation in 1968 [7].

Lautering: after the mashing process, vacuum rotary filters [6] or decanters may be used to remove the insoluble parts from the wort (**Figure 1**).

A process for the continuous production of wort was described by Harsanyi in 1968 [7]. It was substantially characterised by separating the mash continuously by centrifugal action in at least two stages, sparging the largely dehydrated solids fraction with controlled quantities of water removing the dehydrated solids automatically and subjecting the wort obtained to further clarification before delivering it to the brew kettle. The separation of the liquid mash fraction from the solids is accomplished by means of a special type of centrifuge. The centrifuge has a housing in which a conical, perforated drum rotates. The housing has a first chamber with two compartments and separate liquid cutlets and a second chamber for the removal of solids, the second chamber being arranged at the larger diameter drum end. The mash slurry to be separated is delivered into the centrifuge at its smaller diameter drum end. Disposed within the drum is a hollow shaft having two separate liquid passages to which jet pipes are connected. The shaft rotates at a speed slightly less than that of the perforated drum [7].

Similarly, the continuous lautering system Nessie from Ziemann works, introduced to the public in 2016 [8]. The separation of the mash is carried out via four filter units in cascade arrangement, in which the rotary disc filters perform the separation of wort and spent grains. The sparging of the extract is carried out in parallel using a turbulent counterflow extraction [8]. The time saved is about 160 min (34%) per brew [9]. Worts are less blank and contain more fatty acids, more zinc and less polyphenols. This increases the fermentation speed and the flavour stability [10]. Continuously produced worts have different qualities compared to batchwise-produced worts [3].

Wort boiling: the wort boiling process suits to obtain the following objectives [11]:

- Extraction and isomerisation of hop components
- Hot break formation mainly by coagulation of proteins
- Formation of colourant substances
- Formation of reducing aromatic compounds by Maillard reaction
- Evaporation of undesired volatile aroma compounds
- Decrease of the pH of the wort
- Inspissation of the wort
- Sterilisation of the wort
- Inactivation of the malt enzyme fixation of the wort composition.

This can be done continuous and faster at higher temperatures. Continuous high-temperature wort boiling (C) or high-temperature boiling (HTWB) is an alternative boiling system. The idea is quite old as Dummet described such a system in 1958 and Daris et al. in 1962 [20]. At high temperatures of 130 or 140°C, very satisfying wort analysis data could be obtained although very short boiling times of ca. 5 min were used. The wort was heated up in three steps. In the first two steps, vapour from the flash-off chambers was reused. Considerable energy savings could be obtained due to the short boiling time and energy recuperation. Alternative continuous systems have been developed [11]. A boiling aroma was a limiting factor to the temperature. Most breweries using high-temperature boiling were closed or had to reduce the boiling temperature, as some boiling tastes were not beer typical. Reducing the temperature declined the degree of energy recuperation from the vapours.

Chantrell describes the process of a practical 300 hl HTWB in Great Britain, where HTW was popular in the end of the last century [12]. Wort heating and boiling are influenced by the degree of fouling, which is normal for a three-phase system with solid trub, liquid wort and steam [13]. This leads to flooring especially on the heating zone's surfaces and to differences in the quality of the product in a series of batches. Wort quality changes over a series of brews without intermediate cleaning. The heat transport is decreased, and burnt aromas and trub affect the wort. The thermal load on the wort has to be increased because of the heating profile, which has to be adapted in order to compensate the decreasing heat transfer rate caused by the fouling layer [12, 23].

The wort is collected in the existing kettle at approximately 72°C from the lauter tun. Hop addition and adjustments to colour and gravity are made at this stage. The wort is then pumped through the HTWB to the whirlpool separator. Inside heat exchangers the wort temperature is raised in three successive steps to 140°C. At this temperature, the wort is held for 3 min while passing through an insulated holding tube. The wort then passes into an expansion vessel where the pressure is reduced to a predetermined level. In a second expansion vessel, the pressure is reduced to atmospheric pressure. Energy recovery is achieved with the flash vapours of these two expansion stages. They are used to heat up the first two wort heat exchangers. Only the third heat exchanger requires an external steam supply for the trim heating of the

highest temperature. Cleaning of the plant is performed by automatic control and involves three cycles: firstly, the weekly cleaning of the two expansion vessels via spray balls and, secondly, the cleaning of the vapour side of the first and second stage heat exchangers. This cycle is only operated every 2–3 weeks depending on throughput. The main cleaning cycle which follows the wort path through the plant is operated at the end of the 5-day brewing week. Initially, cleaning problems were encountered with the large-diameter holding tubes. These large tubes were difficult to fill, and the low detergent velocity provided no scrubbing action against the protein deposits. The problem has been overcome by the dosing of hydrogen peroxide into these tubes during the caustic cycle. Foaming agents ensure complete cleaning of this section of the plant. The dosage rate for the peroxide is 0.1% by volume of a 30% hydrogen peroxide. For the third stage the heat exchanger is equipped with an automatic self cleaning cycle, using steam to crack the layers usually after one or two thousand hectolitre [12].

At the Meura brewhouse, continuous wort boiling was combined with a hop strainer, if natural hops were used [1]. Decanters or centrifuges were necessary to remove hot break and to avoid yeast slime, especially if continuous fermentation is following. The wort was heated up in-line to boiling temperature. The added hops were homogenised. An adapted agitator assured a sufficient mixing for the trub formation. For the chemical/biochemical reaction of turning the S-methylmethionine into dimethyl sulphide, an external agitation must be provided. Clarification is necessarily conducted prior to stripping to avoid fouling the column with hot trub. The wort-settling tank is needed to recover non-oxidised trub from the hot wort in a continuous way. From the clarification unit, the wort is then stripped by a single pass stripping column. The unwanted volatile components are stripped by counterflow clean steam. The wort is pumped continuously from the bottom of the stripping column through the wort coolers. Because fouling is unavoidable, two duplicate built wort coolers have to assure a continuous cooling of the wort; one wort cooler can be cleaned, while the other one is cooling the wort.

Wort cooling can be done within 50–60 min generating a peak consumption during this period. Compared with batch brewhouses, the heat losses and peak of utilities are lower during continuous processing. While batches are pumped from vessel to vessel, air enters the vessels, pipes and valves at each transfer, thus cooling down the facilities. The transfer of batches also enhances the extract, water and energy losses since vessels are never emptied completely [1]. Water evaporates, and sugars, polyphenols and proteins concentrate, forming layers that have to be cleaned before biofilms come up. Continuous systems can be kept in a stable equilibrium for a longer time and need less cleaning, if kept in a hygienic status. This is even more important in the cold section of a brewery.

5. Continuous fermentation

Continuous wastewater treatments with aerobic and anaerobic microorganisms are big continuous fermentations and show the sensitivity of balancing the biological process. Continuous beer fermentation has to fulfil not only the metabolism of substrate. A system of continuous beer fermentation was patented in 1906 by Van Rijn [2]. In 1953 Morton Coutts patented a process known as continuous fermentation at the Waitemata Brewery in New Zealand, which eventually become DB Breweries [14].

Ricketts (1971) referred to continuous beer fermentation systems which date from the end of the nineteenth century. During the 1960s, while introducing large uni-tanks, interest arose in permanent fermentations. Several systems were developed, and some reached the point of marketability. Some of the anticipated benefits of continuous fermentation were realised, but most breweries, with some notable

exceptions, have continued to use the traditional batch approach, using large-capacity vessels [2].

Coutts created a “wort stabilisation process” that clarified the wort and made it more consistent. He separated the main functions of the yeast into two stages, first the yeast growth and then the fermentation. By splitting these two functions, Coutts created a “continuous flow”. The brewers had to add raw materials continually to the first stage and draw off a steady gain of finished beer from the second stage, thus allowing the process to run constantly [14].

The rate at which wort is produced must be sufficient to supply the needs of the yeast at all the time. Inevitably, this requires a prefermenter wort collection vessel. Downstream of the fermenter the brewery has to be capable of handling a continuous supply of green beer. Consequences of failure in a continuous fermenting system cause a serious threat to production. Emptying, cleaning, starting a new process and establishment of stable running conditions are long procedures that take at least 2 weeks in time [2].

The reactors took the form of a coil or similar elongated form by using multiple tanks with a continuous wort flow. The open continuous culture system may also consist of a stirred reactor to which medium is introduced by an entry pipe [2]. The rate of medium addition can be altered by a frequency-controlled speed pump, which is controlled by sensors checking the state of fermentation by pH, density, turbidity or gas production. Culture yeast is removed from the reactor via a second pipe which is arranged in the form of a syphon.

In 2013 Müller-Auffermann at the Technische Universität München installed a downward-facing pipe with two reaction zones in each tank. Four tanks could be filled and emptied continuously from the top part of the tanks. The tanks were combined to a reaction cascade. They were equipped inside with a central pipe, with open bottom. The bottom connection of the tank could hence be used to discharge yeast cells and other particles during the process [15]. Inoculation and growth medium were mixed at the point of entry and fed simultaneously and continuously into the reactor. Within a discrete “plug” is travelling through the reactor. A minimum of backward and forward mixing had to be assured. So batch growth proceeded. The reactor could be viewed as a continuum of batch cultures. The spatial location is related to culture age. The factors of temperature, inoculation rate and substrate concentration are also influential in a plug flow continuous culture, like in a batch culture. The composition of the culture issued from the reactor is a function of the flowrate. By careful regulation of these parameters, it is possible to establish a steady state at which the product is of a constant and desired composition [2]. Biomass recycling will be a further refinement to be introduced to a plug flow reactor. The biomass is returned to the entry point of the reactor where it is used as inoculum. Used in this way, the reactor requires only to be supplied with fresh substrate [2].

The prolonged nature of continuous fermentation has inherent risks. Extended running times increase the opportunities for microbial contamination. Yeast “variants” may be selected with the concomitant risk of undesirable changes in beer quality. Continuous systems are more sophisticated than many brewery batch fermenters. Skilled personnel must be on-site, night and day, to provide technical support, if a deviation is indicated [2].

In comparison to classical batch fermentation, only one or few fermenting vessels are needed. Furthermore, beer losses are reduced, less pitching yeast is needed, and detergents and sterilants are saved. As long as the process is stable, a consistent beer quality can be expected. Microbiological contaminations or yeast mutation leads to serious consequences [2] especially if no second production line or some beer for blending is available to keep up the delivery capacity.

Continuous fermentation systems, based on immobilised cells, were condemned to failure for several reasons. Engineering problems like excess biomass, problems with CO₂ removal, optimisation of operating conditions, clogging and channelling of the reactor, unbalanced beer flavour, altered cell physiology and cell ageing lead to unrealised cost disadvantages such as high carrier prices at complex and unstable operations [16]. Pilot-plant and full industrial-scale processes showed engineering problems. The carrier material, the reactor design, together with the effect of immobilisation on yeast physiology, and the risk of contamination end up in a hardly predictable flavour profile of the beer produced. Therefore, despite the economic advantages expected, the continuous process has so far been industrially applied only in beer maturation and alcohol-free beer production [16].

The crucial step forward in continuous technology was certainly the development of commercial immobilised yeast reactors. This approach was of sufficient interest to form the subject of an entire European Brewing Convention Symposium “Immobilised Yeast Applications in the Brewing Industry” held in Finland in 1985 [17, 18]. The advantage of immobilised reactors is that very high yeast concentrations are achievable. This allows a very rapid process throughput which is of particular benefit when applied to rapid beer maturation. A single immobilised yeast reactor can eliminate the time-consuming warm conditioning step for diacetyl reduction at the end of a lager beer fermentation [2].

The application of gel occlusion systems in the brewing process, even if associated with many advantages over conventional fermentation technology, has some important drawbacks, particularly diffusional limitations which impact negatively on yeast growth, metabolic activity and beer flavour, Masschelein et al. concluded at EBC Congress in 1984 [18]. Nakanishi et al. recognised that fermentation activity in continuous working fermenters fell gradually during continuous operation of the system. It could be maintained for 2 months by periodic aeration in which 290 mg/g-yeast (dry matter) of oxygen was supplied to the immobilised yeast [17].

Continuous fermentation suits best in breweries making only one style of beer, because its time and capacity consume to stop the process and start up again with a new beer [14]. Immobilised yeast reactors have also found use in new fermentation processes, for example, in the production of low-alcohol or alcohol-free beers [2], where yeast has more clarification tasks than fermenting and propagation. The major strength of the batch system, using several vessels, is that it is able to cope with seasonal or shorter-term fluctuations in demand. It can easily be adapted to vary the spectrum of production of several different beer varieties and qualities. On the other hand, benefits of continuous fermentation are realised when the systems are operating at a stable status for a long period of time with minimum downtime for changes in beer quality [2].

6. Maturation

Some of these yeast metabolism byproducts (vicinal diketones, acetaldehyde, dimethyl sulphide) impart undesirable flavours to the green beer. The main aim of maturation is to reduce the concentration of such unfavourable flavour compounds in the green beer, to saturate the final beer with CO₂ and to remove the haze-forming components from beer within 7–30 days [16]. Fumigation with CO₂ under counter-pressure to avoid too much foam may strip the unwanted flavour. The flavour can be removed from the CO₂ with active carbon so that the CO₂ may be

collected, compressed and used for further tasks. Continuous clarification is best done with centrifuges or decanters.

7. Filtration

Filtration and stabilisation of the beer are carried out in order to achieve microbial, colloidal and flavour stability so that no visible changes occur for a long time and the beer looks and tastes the same as when it was made [16]. Particular for higher amounts of yeast cells, tangential flow or crossflow filters are good prefilters before flash pasteurisation or membrane filtration. Although batch flushes can extend the continuous filtration of a crossflow filter, fouling layers will clog the membranes. A chemical recovery of the filter modules is necessary; the continuous process has an end. Usually bright beer tanks collect a batch for the final quality control, and they are the buffers for the following filling of the beer in bottles, cans, kegs or road tankers.

8. Continuous bottling

The most expensive and labour-intensive part of the value creation in breweries is the bottling part. Here most breweries produce continuously, as several machines are needed. Depalletisers for new or crated return bottles, washing machines or rinsers, inspection machines fillers, pasteurisers, labelling machines, packers, wrappers, shrink machines and palettisers run more or less continuously. Stops and interruptions have to be buffered by the conveyers, usually able to keep machines running, while the other needs time to repair so that the previous or following machines need not stop. Modern bottling lines have frequency-controlled conveyers and machinery so that the assembly, connected by system bus, can alter their speed to keep up the continuous production.

The big challenge is changing of the products, the beer type, the labels or the shape and size of the bottles. In bottling, when the beer arrives filtered, sterile and stable, mostly physical deviations have to be handled. Product safety has to assure clean, not contaminated bottles. Camera systems or even gamma or X-ray is used to check the bottles, cans or kegs. Rejected containers have to be replaced by the following shipshape containers. Bottle burst leads to splinter showers, where open bottles have to be removed, eventually contaminated by sharp-edged glass.

Mistakes in this process certainly propagate downstream, if not corrected immediately. A dirty bottle becomes a dirty filled and corked bottle, is labelled and packed and—in the worst case—is sold and consumed. Sensors and camera systems should check the system at the highest accuracy possible, as the process goes on and might lead to big amounts of unsafe products at the far end of the beer production and the intersection to the customers and consumers. The more precise the process is performed, the safer the product and the more the consumers' expectations can be met.

9. Inaccuracy of production, measuring, controlling and quality forecast

One problem of continuous fluid dynamics is the dwell time in the system. Flow conditions ought to be simulated in flow models. These have to be simulated and calculated to predict rheological behaviour and chemical or biochemical reactions [13]. In production methods, biologically grown raw materials or process measurements have a certain inaccuracy or mistake, and results cannot be determined. They just can be estimated mathematically.

The average remaining time in a system is not similar to the real remaining time in a system. Molecules or particles entering a system at the same time may have different remaining times [13]. If there are two or more phases, like fluid and solid or gas particles, the continuous phase (usually the fluid of the beer and the foam) may behave totally different from the solids and the gas phase (bubbles) [13]. Coalescence will be influenced by the collision frequency and the behaviour of the substances during the phases [13]. Biochemical processes have lots of influencing factors, like temperature, pH value, viscosity, surface tension, osmotic and hydrostatic pressure, concentration gradients, mechanical influences, electrical effects, zeta potential and many more. Especially microorganisms change their behaviour under different conditions. As evolution does not stop at the brewing vessels, genetic deviations may cause different behaviours of raw materials and microorganisms.

If more than one species is present, synergetic or suppressing effects may end up in biofilms and uncontrollable developments. Working with just one species—mostly *Saccharomyces*—is quite predictable in its final products. As soon as more species come up, things get more and more unpredictable. Hygiene helps to keep processes under control. Dead zones may become lively areas, and biofilms have to be avoided. Hygienic difficulties in cleaning have to be respected, and in fact, continuous systems cannot be cleaned as often, as batch containers if used for a long time.

This causes problems, especially if brands need to have a constant quality to fit to the consumers' expectation which connected to the brand. Lots of homogenisation equipment during continuous production achieve a dense remaining time in the reactors. Energy, shear forces and moving parts are usually combined with abrasion of wear parts, which means a continuous change of quality of the machinery. Preventive maintenance needs to stop the processes and to start them again.

10. Mathematical, physical, chemical and biological limits by error propagation in continuous production

A lot of factors have an influence on each step of malting and brewing. This ends up in a broad range of quality factors. Especially biologically balanced equilibriums react to changing conditions by complicated, not predictable effects, which can hardly be measured or recognised by sensors (Table 3).

Each quality parameter and each sensor, used during the processes, have its specific standard deviation and impreciseness during measurement. This can be respected, when intermedia products are checked for their quality. Corrective arrangements can be used to reach the final quality aim. During continuous production error, propagation may lead to a huge deviation in quality, which is also caused by the given impreciseness of the sensors who should avoid this, especially if lots of sensors are used in following steps to automatically control the continuous production [21].

An imprecise thermometer in the mash process will lead to different amounts of sugars or proteins, which can behave differently in the wort vessel than the wanted product. This may lead to different colours or yeast behaviours. The thermometers, used during fermentation, have a certain deviation as well, which might lead to different metabolisation products. They can be a favourable substance for other yeast or bacteria strains which also create unwanted flavour products. Sensors may detect but also have a deviation which allows unwanted processes. If sensors show a deviation to the quality aims, a continuous system should be able to adjust the process to the predetermined values. If this is not possible, the process has to be stopped. Analysis

Gas phase	Liquid phase (continuous)	Solid phase
Volume	Temperature	Form
Pressure	Viscosity	Size
Temperature	Surface tension	Surface, roughness
Gas equilibriums	Density	Density
Bubble size	Hydrophobic substances	Zeta potential
Bubble form	Hydrophilic substances	Hydrophobic liquids
Molecular size	pH	Hydrophilic liquids
Heat capacity	Heat capacity	Heat capacity
Altered/influenced by		
Temperature	Temperature	Temperature
Pressure	Shear forces	Shear forces
Microorganisms	Microorganisms	Microorganisms
	Enzymes	Enzymes
Time	Time	Time

Table 3.
Influencing physical and microbiological factors during beer production.

Propagation Errors - General Formula

Suppose that y is related to n independent measured variables $\{X_1, X_2, \dots, X_n\}$ by a functional representation:

$$y = f(X_1, X_2, \dots, X_n)$$

Given the uncertainties of X 's around some operating points:

$$\{\bar{x}_1 \pm \Delta x_1, \bar{x}_2 \pm \Delta x_2, \dots, \bar{x}_n \pm \Delta x_n\}$$

The expected value of \bar{y} and its uncertainty Δy are:

$$\bar{y} = f(\bar{x}_1, \bar{x}_2, \dots, \bar{x}_n)$$

$$\Delta y = \sqrt{\left(\frac{\partial f}{\partial X_1} \Delta x_1\right)^2 + \left(\frac{\partial f}{\partial X_2} \Delta x_2\right)^2 + \dots + \left(\frac{\partial f}{\partial X_n} \Delta x_n\right)^2} \Bigg|_{(\bar{x}_1, \bar{x}_2, \dots, \bar{x}_n)}$$

Figure 2.
Mathematical estimation: example for additive error propagation [22].

of the intermedia product may help to decide how the quality targets can be reached by the following process step, in the way batch processes are successfully managed.

The deviations in a naturally given physical, chemical and biological concentrations sum up and propagate by each sensor deviation and error used in the process. Calibration might help to a certain extent, but the amount of sensors is growing in continuous processes, so the amount of possible imprecise information is steadily increasing with the amount of measurements and control valves and regulations, which also have a certain deviation. Measurable substances like diacetyl, gravity, conductivity and turbidity are useful, but they are just single parameters in a bunch of varying aroma particles, dependent on microbiological, chemical and physical balances.

In statistics, "propagation of uncertainty" also called "propagation of error" is the effect of variable uncertainties combined. Errors, or more specifically random errors, result in an uncertainty that builds up during long-lasting consecutive

differences in production by treating different phases							
Phases	mashing	lautering	boiling	fermentation	maturation	filtration	bottling
solids	grain	spent grain	trub, hops	trub, yeast	trub, yeast	trub	trub
fluid	mash	wort	wort	beer	beer	beer	beer
gas			steam	O ₂ , CO ₂	CO ₂	CO ₂	CO ₂
production inaccuracies from measurement deviation, influencing the control of the process							
Time [min]	◁	◁	◁	◁	◁	◁	◁
°C	◁	◁	◁	◁	◁	◁	◁
% o.g.	◁	◁	◁	◁		◁	◁
Trub EBC		◁			◁	◁	◁
bar				◁	◁	◁	◁
Aroma				◁	◁	◁	◁

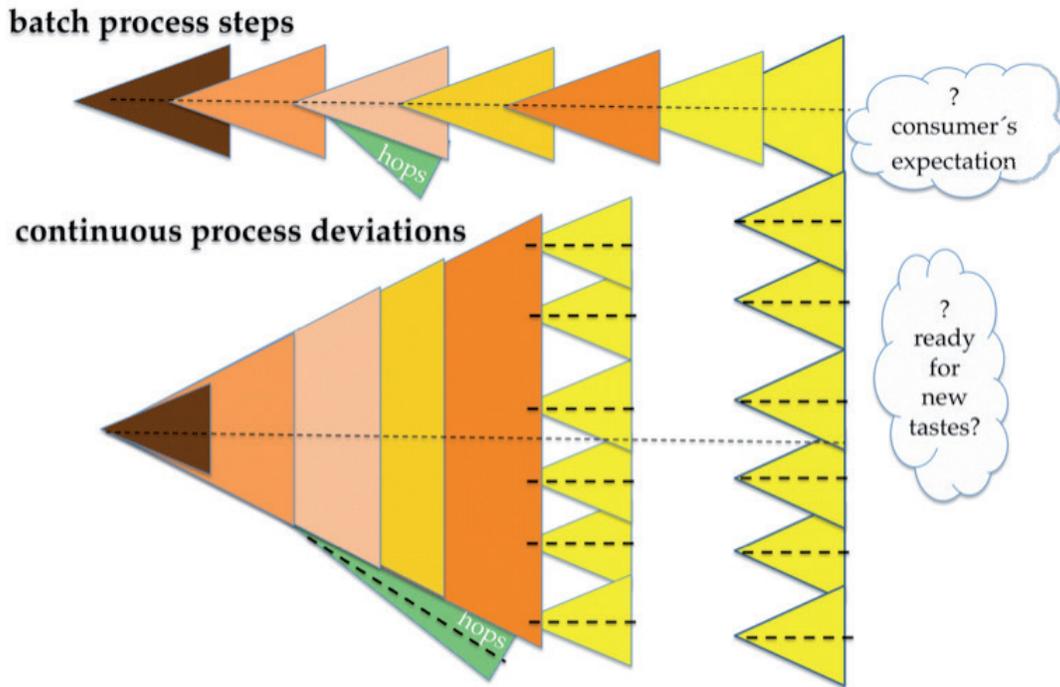


Figure 3.
Deviations in batch and continuous brewing processes.

processes. Measured values are necessary to control the process. All measurements have uncertainties due to limitations (**Figure 2**). Instrument precision and other deviations propagate due to the combination of variables in the function [19].

If biological changes occur in raw materials or microorganisms, errors do not add but multiply, or exponentiate, as several factors change: aromas, natural substances, pH, viscosity, chemical balances, concentrations, compositions, sublimation, dissolving, evaporating, etc. Respecting the rheologically unpredictable behaviour of altering three phases during rheological processes [13], a constant and planned quality can only be expected for a certain time; quality changes and emptying and cleaning of the system become necessary.

Continuously changing products like mash, fermenting of green beer has to come to a stable and defined quality, which fits to the consumers' expectation. This is traditionally achieved by cold stabilisation during maturation, which is also a possibility to check and adjust quality, to blend the beers, and it is a buffer before bottling and racking. Filtration and pasteurisation help to stop the most biological and enzymatic processes. Especially before bottling a quality check has to be conducted, to avoid faulty products being bottled. The product will be kept during distribution and at the consumer's place for a certain time, where it should not change anymore. Finally the consumer's expectation cannot be adjusted to an unpredictable quality (**Figure 3**).

11. Conclusion

Stepwise batch production has been added by continuous brewing processes for more than 100 years. Calculations may predict the results in biological processes to a more accurate degree, if computers obtain more and more data to use. The results in the end are estimations, relying on the number of factors in relation to their influencing parameters. The possibility to measure these factors need to have a known accuracy. This will stay the biggest challenge, as long as natural ingredients and microorganisms play a main role in malting and brewing. Fermenting with more than one yeast strain quality, prediction falls back to the times of spontaneous fermentation, where only few products were of a good taste by accident. The same thing occurs, if contaminations get into the continuous systems, when cleaning always implies a long interruption of the process, especially a long time to adjust the following process up to a stable equilibrium.

Many substances in beer are known, many not. Some substances or physical properties are useful to define the quality of the beer and the intermedia production steps. Few parameters can be used to control the brewing process in the direction of a defined quality aim. All of the raw materials, the determination methods, the regulation equipment and the biological reactions of the microorganisms have deviations, some of them are not measurable or known yet. In a batch process inter-stage products like malt, wort or fermented beer can be checked, and the following processes can be used to adjust the quality goals. Reactions to the deviations in continuous processes should set the system back to the target conditions. Combining several steps to a continuous process with continuous adjustment can be controlled by a self-learning by fuzzy logic or artificial intelligence. As these computers need data from precise sensors to control precise valves, stirrers, pumps, etc., this will lead to a predominantly maintaining, calibrating and scrutinising reaction to the system instead of brewing and creating the quality of the beer.

Nowadays a continuous step is followed by a batch step. The possibility in adjusting the quality with following processes should be given. Also blending needs buffer capacities to equalise the beer to consumer's expectation. For offering different beer types, also blending beverages are necessary to be added. The continuously produced beer might supply a base beer, which is blended before filtration with other batch process beers or water, aromas and lemonades in a nontraditional way.

The brewing process can be performed in steps, continuously and automatically. Perhaps one day continuous processes will be longer stable. The processes may also expire in constant quality results. But brewing is fun, fun that should not be left to the machines.

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References

- [1] Bonacchelli B&HF. The Meurabrew the Brewhouse of the Future! [Online]. Available from: <http://www.meura.com/uploads/pdf/Meurabrew%20Paper.pdf> [Accessed: March 18, 2019]
- [2] Buffalo_Brewing_Blog. Buffalo Brewing Blog » Brewery Convention [Online]. 2018. Available from: <https://www.buffalobrewingstl.com/brewery-convention/continuous-fermentation.html> [Accessed: March 17, 2019]
- [3] Kunze W. In: Lebensmittelindustrie MfBlu, editor. Technologie Brauer und Mälzer. 5th ed. Leipzig: VEM Fachbuchverlag Leipzig; 1979
- [4] Schuster WN. Die Bierbrauerei Erster Band Die Technologie der Malzbereitung. Stuttgart: Ferdinand Enke Verlag; 1976
- [5] Krones. Krones.com. [Online]. 2019. Available from: https://www.krones.com/media/downloads/waermetauscher_en.pdf [Accessed: April 4, 2019]
- [6] Narziß L. Back W. Die Bierbrauerei. Band 2: Die Technologie der Würzebereitung, 8th ed. Weinheim, USA: Wiley-VCH Verlag GmbH & Co. KGaA, John Wiley & Sons Inc; 2009
- [7] Harsanyi DE. Kontinuierliche Schnellabläuterung nach dem Pablo-System. Brauwelt International. 1968;**108**(Nr. 45/46, 5./7):843-845
- [8] Nessie Ziemann Holvrieka. Journal Beer [Online]. 2016. Available from: <https://journal.beer/2016/11/14/nessie-revolutionizes-the-brewhouse-novel-mash-filtration-process-by-ziemann-holvrieka/> [Accessed: March 20, 2019]
- [9] Klaus Wasmuht DE. Experience is the most Challenging Test. Brewing and Beverage Industry International. In: Sachon VW, editor. Mindelheim: Schloss Mindelburg; 2019
- [10] Wasmuht K, Schwill-Miedaner A. With Omnium to Optimum. Rust, Baden: VLB Berlin; 2019
- [11] Willaert RG, Baron GV. Wort boiling today—Boiling systems with low thermal stress in combination with volatile stripping. *Cerevisia. Belgian Journal of Brewing and Biotechnology.* 2001;**26**:217-230
- [12] Chantrell NS. Practical experiences in the production of wort by continuous high temperature wort boiling. *MBAA Technical Quarterly.* 1984;**21**:166-170
- [13] Kraume M. Verfahrenstechnik. 2nd ed. Berlin, Heidelberg: Springer Vieweg; 2012
- [14] Brooks JR. Continuous Fermentation—Volume 29, Issue 4 [Online]. 2008. Available from: <http://allaboutbeer.com/article/continuous-fermentation/> [Accessed: March 17, 2019]
- [15] Auffermann-Müller K. More Sustainable Way to Brew Beer: Non-Stop Fermentation Saves Resources May 28, 2013, Technical University Munich. Read more at: <https://phys.org/news/2013-05-sustainable-brew-beer-non-stop-fermentation.html#jCp> [Online]. 2013. Available from: <https://phys.org/news/2013-05-sustainable-brew-beer-non-stop-fermentation.html> [Accessed: March 18, 2019]
- [16] Brányik T, Vicente AA, Dostálek P, Teixeira JA. Continuous beer fermentation using immobilized yeast cell bioreactor systems. *Biotechnology Progress.* New York: American Institute of Chemical Engineers (AIChE); 2005; **21**(3):10
- [17] Nakanishi K, Onaka TIT, Kubo S. A new immobilized yeast reactor

system for rapid production of beer.
In: European Brewery Convention
Proceedings of the 20th Congress
Helsinki, 1985. Helsinki: European
Brewery Convention; 1985. pp. 331-338

[18] Masschelein CA, Carlier A,
Ramos-Jeunehomme C. The effect of
immobilization on yeast physiology
and beer quality in a continuous and
discontinuous system. In: Convention
EB, editor. European Brewery
Convention Proceedings of the 20th
Congress Helsinki, 1985. European
Brewery Convention; 1985. pp. 339-346

[19] Edu H. Physical Sciences 2 Harvard
University, Fall 2007 [Online]. 2007.
Available from: http://ipl.physics.harvard.edu/wp-uploads/2013/03/PS3_Error_Propagation_sp13.pdf [Accessed: April 7, 2019]

[20] Daris AD, Pllock JRA, Gough PE.
Journal of Institute of Brewing.
Weinheim, USA: John Wiley & Sons
Inc.; 1962;68:309

[21] Belabbas B. DLR Institute of
Communications and Navigation
Multi-Sensor Integrity [Online].
Available from: https://www.dlr.de/kn/en/desktopdefault.aspx/tabid-7570/12813_read-32121/gallery-1/216_read-2/

[22] Gehlot T. Slide Share Error Analysis
Statistics [Online]. 2014. Available
from: <https://www.slideshare.net/tarungehlot1/error-analysis-statistics>
[Accessed: March 22, 2019]

[23] Voigt DJ, Wasmuht K. Fouling
during wort boiling—Effects on wort
quality. Master Brewers Association
of the Americas MBAA TQ.
2006;43:207-210