Stirring stuff

Getting the best out of cylindroconical fermenters

In the world of commercial brewing cylindroconical fermenters continue to be the vessels of choice. Certainly when new brewery builds are planned the installation of such vessels is an inevitability. This dominance is for very good reasons as the cylindroconical design affords many advantages.

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Their enclosed nature and stainless steel construction provide excellent hygiene, they can be used for any beer quality and in theory at least, their surface area to volume ratio provides efficient heat transfer via external cooling jackets. Collection of CO_2 is easily accomplished, wetting losses are low and the cone facilitates crop collection and separation. When arranged in tank farms they have a relatively small footprint and many vessels may be conveniently serviced by common systems for filling, pitching, cropping and emptying.

In light of such a dazzling list of advantages what could possibly be amiss? Maybe not a great deal but I would venture to suggest that if the reader makes a critical examination of these advantages it may be concluded that the majority are simply good engineering solutions to the problems posed by the physical requirements of the process. Apart from an appreciation of the need to provide sterile oxygenated wort, pitched at an appropriate rate and cooling sufficient to maintain the temperature at a desired value, few of the design parameters pay any heed to the actual process of fermentation and in particular the various triggers that direct the metabolism of yeast cells. Of course, brewers might say that fermentation is the controlled conversion of wort into green beer using yeast as a catalyst; however, it should be remembered that from the perspective of yeast, green beer is nothing more than the spent growth medium!

In this article I will provide evidence that if more attention is paid to the reactions of yeast cells to the conditions that they encounter during fermentation it is possible to produce much greater consistency than is currently achieved. This improved consistency applies to cycle times, yeast growth extent and beer analysis. Furthermore, it is possible to guarantee that yeast crops will have a high viability, to reduce cycle times and to increase beer yield. Some of these gains are achievable by paying attention to the management of fermenters, particularly during the initial fill, others require some modification to fermenter design. With regard to the latter, I will suggest that the time is right to take a critical look at current cylindroconical design. Perhaps it is time that we open a discussion to consider how we might move on to the next generation of vessels which more properly meet the needs of the modern industry.

In previous articles (*Brewer and Distiller International*, September 2007, August 2008) I have discussed some of the perhaps unconsidered consequences of managing very large fermentation vessels. Most notably the fact that prolonged filling times require the user to make decisions as to when pitching and oxygenation should occur; furthermore, the perhaps counter-intuitive fact that thermal convection currents and CO_2 generation provide very inefficient mixing such that the contents of vessels are heterogeneous for much of the time.

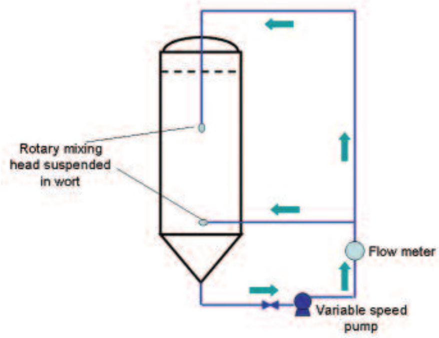

Figure 1. Diagram showing possible systems for mixing fermenters using a pumped loop system. The wort is taken from the cone and may be returned to the vessel either via a top fitting in which the entry point extends below the liquid surface (this may be part of the existing CIP system); or, the re-entry point may be at a point close to the top of the cone.

The ineluctable conclusion that devolved from these studies was that provision of mechanical agitation in large fermenting vessels is desirable. Here I would like to describe how this might be done and to discuss the effects of efficient agitation on fermentation performance.

Mixing and matching fermentations

Brewers are probably unique in the field of biotechnology in that they have never seen fit

Typical arrangements in the cellar below conical FVs. Pipe fences in use at Ulm in Germany and Pottsville in the USA.

Putting finishing touches to the tank farm at Carlsberg, Fredericia in Denmark. 22 tanks were moved from the closed plant at Valby in Copenhagen, Denmark.

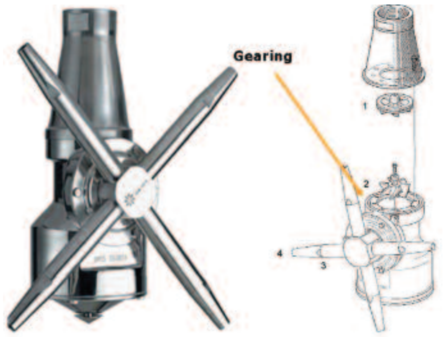

Figure 2. Rotary mixing heads by ISO-MIX A/S.

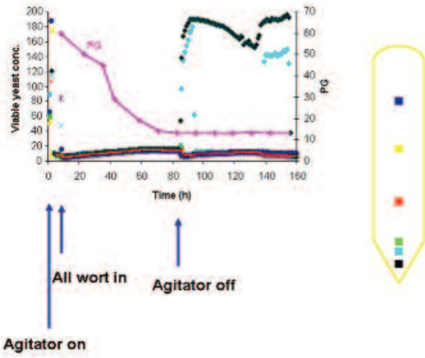

Figure 3. Diagram showing viable yeast concentration at various heights of the central core of a 15oP lager fermentation performed in a cylindroconical with a capacity of 1600hl. The colour coding indicates the point in the vessel at which the measurements were made. The gravity profile, based on off-line analyses, is also shown.

D cellar at Fosters in Melbourne, the home of 6600hl 7-metre diameter monster vessels.

to provide fermenters with mechanical mixers. Perhaps this is explainable in that visual observation of actively fermenting wort would suggest that natural mixing is good; indeed, the word fermentation derives from the *Latin fevere*, to boil. Coupled with this is the need to allow the yeast to form a crop such that it can be separated from the green beer. Whatever the reasons might be, most fermenters, unless designed for unitank operation, tend not to have mechanical agitators. Retrofitting of bladed impellors is expensive since the cooling jackets may have to be broached. An alternative approach is to use a pumped loop system (Figure 1).

This arrangement is comparatively inexpensive to fit to existing vessels. It may use the existing CIP system, simply by extending the top inlet point such that it is submerged when the vessel is full and thereby overcome a common objection in that efficient cleaning is easily accomplished. Alternatively, the return point can be close to the cone in which case it can be used during a critical filling period without the generation of excessive fobbing. In this latter point the loop is also made part of the CIP circuit.

The rate of pumping can be varied to suit the particular vessel. A key part of the system is the use of a rotary mixing head of the type designed for CIP. In the trials described here the loop systems and mixing head were designed and fitted by the Danish company, ISO-MIX A/S – Figure 2. These heads provide highly efficient mixing of the contents of vessels but without the generation of excessive shear forces which might be thought by some to damage yeast cells.

Effect of mixing on fermentation performance

Previous reports have described investigations designed to study the dispersion of yeast cells in during fermentation in conical vessels. This was accomplished using an array of Aber Instruments biomass probes sealed in waterproof enclosures and suspended at various depths along the central longitudinal axis of the vessel. The results of a trial using an in-tank impeller-type mixer to agitate the contents of the vessels is shown in Figure 3.

It may be seen that during the period in which the contents of the vessel were forcibly mixed (0–85h), based on viable yeast concentration, conditions were essentially homogenous. As soon as the agitation was discontinued the yeast very quickly formed a crop in the cone. This serves to illustrate how the brewer may use this arrangement and take a pro-active approach to the control of yeast dispersion. In so doing the time of cropping can be controlled with greater certainty than is usual and thereby exposure of yeast to the relatively hostile conditions of the cone can be minimised.

It would be predicted that the better control of cropping might be reflected in improvements in crop viability and indeed this did appear to be the case (Table 1). It may be seen that on average the crops removed from the agitated fermentations were marginally bigger than those from unstirred controls. The viability of the former was on average 7% higher than the latter.

Table 1

	Total crop weight (kg)	Total solids (% w/v)	Viability (%)
Trials (mean of 17)	5038	36.7	93
Controls (mean of 22)	4750	36.0	86

Table 1. Analysis of yeast crops removed from agitated and non-agitated fermentations removed from a cylindroconical fermenter with an operating volume of 1600hl. In the case of the controls the crops were removed after the vessel was crash cooled to 4°C. In the case of the trials the crops were removed 24h after the agitation was discontinued, without prior cooling of the beer.

Table 2

Brewery	Cycle time reduction (%)	Criterion
A	29	Time to VDK
B	15	Time to VDK
C	10	Time to completion of cool
D	16	Time to completion of cool
E	20	From start of fill to end of CIP

Table 2. The effect on cycle time, as judged using the criteria indicated, of the use of a pumped loop system at five different commercial breweries. In each case the figures are based on mean values obtained with agitated trials and compared with contemporary unstirred controls.

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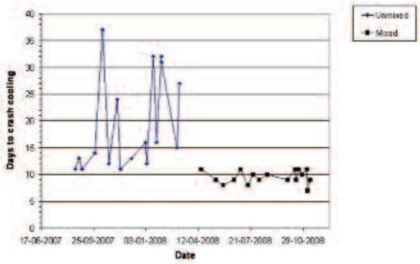

Figure 4. Cycle times, measured as time to crash cool, for commercial fermentations (up to 5000hl) stirred using pumped loops (250hl/h) compared with contemporary unstirred controls. The trials and controls did not differ in any respect other than the application of stirring.

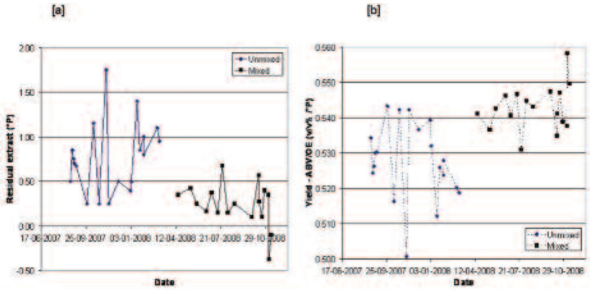

Figure 5. A comparison of residual (apparent) extract [a] and ethanol yields, expressed as the amount of ethanol formed / °P fermented [b], for unstirred and stirred fermentations carried out at a commercial brewery during the time period shown using wort with an initial concentration of 18.5°P and vessels with a capacities up to 5000hl.

Cycle time effects

In many breweries fermentation is rate-determining for the whole brewing process. In terms of both capex and revenue costs reducing cycle times is beneficial. The data presented in Table 2 (previous page) indicates the effects on cycle time of using the pumped loop system at five different commercial breweries.

It may be seen that in each case there was a significant reduction in cycle time associated with the application of forced stirring. This is a remarkable finding when it is borne on mind that in each case, vessel geometry, wort concentrations and type and yeast strain were different.

Quicker fermentations may be attractive to many brewers but by no means all; however, every brewer should be seeking to deliver as consistent a performance as is possible. Aside from the advantages that this confers in terms of production scheduling it would be predicted that consistent fermentation would also translate into consistent yeast growth and most importantly consistent beer. The data shown in Figure 4 would seem to provide conclusive evidence that the application of forced agitation leads to significantly less variability in cycle time. Clearly the reduction in cycle times was confirmed but, perhaps more significantly, a dramatic reduction in the variability of cycle times was also observed.

Fermentation efficiency

The fact that the application of forced agitation produces more rapid fermentations suggests that in conventional unstirred controls the conditions are in some way limiting. This restriction might be simply that the heterogeneity prevents efficient contact between yeast cells and external nutrients. In addition, it is possible that poor mixing has an adverse effect on passive transport mechanisms. Thus, where transport of metabolites into and out of yeast cells requires a concentration gradient it is conceivable that low rates of fluid flow and/or efficient dispersion of yeast cells might hinder such processes. It is noteworthy that for all the trials described here the resultant beers were all considered true to type. This is interesting in that if agitation had had a profound effect on yeast growth it might have been predicted that shifts in the spectrum or overall concentrations of flavour-active metabolites might have occurred.

Apparently this was not the case. In another sense poor mixing or premature formation of the yeast crop might have been expected to affect the end of fermentation. In other words, the formation of many flavour-active metabolites is associated with the assimilation of wort components such as free amino nitrogen and this occurs in early to mid-fermentation. At the end of fermentation yeast growth has obviously ceased; nevertheless, yeast cells would still be capable of taking up residual extract and generating ethanol.

A comparison between stirred and unstirred fermentations of ethanol yields and residual extract seems to confirm that this is the case (Figure 5).

The gains in consistency of cycle times observed in stirred fermentations (Figure 4) were mirrored in the terms of the consistency of residual extract (Figure 5a). It was also observed that in the case of the stirred fermentations the residual apparent extract was lower than the unstirred controls and there was a concomitant increase in ethanol yield (Figure 5b). On average the ethanol

Plenty of room to work below these conicals at Shiner in Texas USA.

A typical skyline at a modern brewery, these vessels are at Heineken's Royal plant in Manchester, UK.

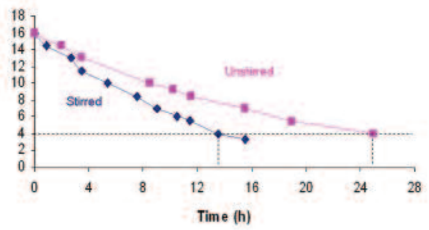

Figure 6. Comparison of the temperature of beers during crash cooling of a conical fermenter with a capacity of 1800hl either unstirred or using a loop system and a pumping rate of 250hl/h.

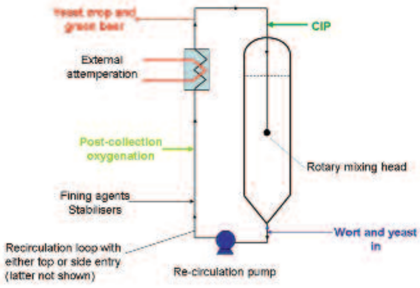

Figure 7. The principal features of a potential new design for a cylindroconical fermenter.

yield of the stirred fermentations was 2.8% higher than the contemporary unstirred controls. Clearly, taken in conjunction with the gains in consistency, this increased yield should for many brewers provide a short pay-back time for the costs of fitting the mixing system.

Fermenter cooling

Crash cooling in large vessels via wall mounted cooling jackets is not particularly efficient; indeed, where the practice is undertaken it constitutes a significant part of the total fermentation cycle time. This is largely a consequence of the fact that at the end of fermentation CO_2 evolution rates are low as are rates of fluid flow and therefore convective heat exchange between the body of the beer and the cooling jackets is inadequate. It would be predicted that the application of agitation would lead to improvements. Using the pumped loop system this supposition was confirmed (Figure 6). In the case of unstirred control fermentations it required 25h for the temperature of the beer to be reduced from 16°C to 4°C. Using an identical fermenter fitted with the pumped loop system the cooling time was reduced to 13.5h.

Fermenter design

I hope that the evidence presented in this article, as well as that in previous offerings, is sufficiently striking to convince readers that the provision of forced agitation is desirable. Whilst this might be achieved in many ways the pumped loop system is particularly attractive since it may be easily fitted to existing vessels. More importantly the loop can be used for additional duties. These could be incorporated into a new design of vessel which better suits the needs of modern high gravity and high capacity fermentations (Figure 7).

Of course, the design shown in Figure 7 would not suit all duties; however, I hope it might stimulate some discussion. The pumped loop system, apart from providing homogeneous conditions, would also eliminate the variability due to the use of vessels with differing capacity and aspect ratio. Although mixing improves heat transfer it would, where vessels are used exclusively for primary fermentation, perhaps be sensible to dispense with the wall cooling jackets and instead use an in-line heat exchanger. The latter could be used much more efficiently for attemperation during primary fermentation and for crash cooling during run-down. This would be possible since it has been shown that the yeast can be made to crop by discontinuing pumping at an appropriate time in the fermentation (Figure 3). In order to minimise yeast stress the crop would be removed warm, possibly using the heat exchanger to cool it, prior to transfer to storage vessel. Of course, if the yeast is to be re-pitched within a relatively short time (<12h) it might be less stressful to not bother with intermediary chilling.

The wort and yeast would be introduced into the base of the vessel, as usual. In the early stages of this process the pitched wort would be re-circulated and in so doing ensure good dispersion of the yeast during the critical early phase of fermentation. The provision of the loop would facilitate the post-collection addition of oxygen. This ability to control the time of exposure of yeast to oxygen would provide a useful facility for regulating beer esters. Of course, it may also be argued that conventional in-line oxygen dosing systems sited at the paraflow do not necessarily provide precise control of wort oxygenation since different length pipe runs and gas breakout at fermenter fill are likely to produce some variability. In this regard the ability to add some or all oxygen directly to the vessel, during or after fill, might be beneficial. Certainly it would ensure that the yeast was given the maximum opportunity to assimilate the oxygen and reduce the chances for undesirable wort oxidations. In unitank operations the loop would provide an efficient method for dosing stabilising and fining agents.

In conclusion, cylindroconical fermenters are commonly thought of as being the acme of modern vessel design. Of course in actuality they have been in use for nearly 100 years (Nathan, L. (1930) *Journal of the Institute of Brewing*, 36, 544-550).

Apart from a move from aluminium to stainless steel their design has changed little since their introduction. Perhaps it is time to move on?

Even the vessel cones do not need to be enclosed. Frost protection is essential for a chilly winter in Virginia though – MillerCoors at Shenandoah, USA.

Acknowledgement

This article was based upon a presentation made at the recent EBC held in Hamburg which featured Dr Mikkel Nordqvist of ISO-MIX A/S as co-author. This author is indebted to Mikkel who both designed and carried out the majority of the trials the results of which are presented here.