

# **Improved control of yeast pitching rate using the Aber™ Yeast Monitor – financial implications**

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## **1 Introduction**

In order to produce consistent fermentation performance and controlled beer quality, it is essential that yeast stocks are managed in such a way that variability in physiological condition is minimal. Providing that this is accomplished and there is adequate control of other important variables such as wort composition and oxygen concentration, fermentation performance is governed, in a large part by the yeast pitching rate. It follows that procedures that lead to precise and repeatable control of yeast pitching rate will result in consistent fermentation performance (2,3).

In brewing, yeast concentration is traditionally quantified by direct counting of cells using a microscope and haemocytometer or indirectly by centrifugation and determination of the spun solids content of yeast slurries. In both cases the viability is determined by staining cells with an exclusion dye such as methylene blue (5,7,8). These methods are time consuming and require skilled personnel for their performance. Even so the absolute precision and repeatability of these methods is poor. The Aber™ Yeast Monitor (1,2,4,6,9,10), an on-line probe that measures live yeast concentration, overcomes many of the problems associated with traditional manual methods of yeast concentration measurement. Here an attempt is made to quantify, in financial terms, the advantages of using and Aber™ Yeast Monitor for the control of yeast pitching rate.

Financial calculations are based on a brewery producing approximately 1.6 million hl of a single quality of keg lager beer (4.0% abv) from a 15 Plato high gravity wort.

## **2 The Aber™ Yeast Monitor measurement principle**

The Aber™ Yeast Monitor system incorporates an on-line probe with a four-pin electrode system. The two outer pins produce a radiofrequency electric field and the two inner pins measure the current. The electric field causes ions in the suspending medium (e.g. wort or beer) and the cytoplasm of yeast cells to migrate towards the two respectively oppositely charged electrodes. As the yeast plasma membrane is non-conducting and ions cannot freely move across it, a build-up of charge occurs and the yeast cells become polarised causing them to act as tiny capacitors. Non-viable cells or cells with a damaged membrane do not interfere since movement of ions across such membranes is not impeded and therefore these cells do not become polarised and there is no build up of charge. Trub and other non-yeast solids also have no effect on the capacitance signal as they do not possess a polarisable membrane. The measured capacitance due to intact yeast cells is directly proportional to the amount of viable yeast within the sample. Output is linear over a wide concentration range.

The Yeast Monitor is suitable for in-line application in brewing and has been used widely as an aid to yeast management in operations such as yeast pitching, cropping, krausening and control of feed rate to centrifuges. Historically the instrument has been used to measure high yeast concentrations such as pitching yeast slurries. Advances in the technology now allow reliable measurements to be made in more dilute yeast suspensions such as those found in fermenting vessels.

Measurements are made using a 25mm probe that for in-line use fits into a modified Tuchenhausen Varivent (or equivalent) stainless steel instrument housing. The probe is composed of an inert plastic resin that is resistant to brewery CIP processes such as hot caustic cleaning and steaming. Attached to the probe is an IP65 rated head amplifier. The amplifier and probe assembly are connected to the main electronics module via a special cable that can be extended up to 100metres. The yeast concentration output can be via a 4-20ma current loop, Profibus or an RS232 serial link for connection to a PLC for use in a control system. Additional outputs are provided which allow the controlling PLC to detect various alarm conditions indicative of malfunction or process irregularities. The most recent Yeast Monitor instrument, the Model 720, which has an integral IP 65 enclosure and a four input multiplexer, is shown in Figure 1.



**Figure 1 Yeast Monitor Model 720**

### **3 Potential cost savings due to improved pitching rate control**

Precise control of pitching rate attracts several benefits. These relate to process and product consistency and also to process efficiency. In addition, automatic control of pitching rate eliminates the need for most laboratory analyses of yeast slurries. This may reduce (skilled) manpower costs.

#### **3.1 Product consistency**

Pitching rate control, together with other relevant fermentation process control variables, regulates the extent of yeast growth. By inference, pitching rate control has the potential to influence the formation of beer flavour components known to be related to yeast growth. These include esters and higher alcohols which together form two of the most important groups of beer flavour compounds.

Several studies have shown that inconsistency in yeast growth results in variable beer quality (2,5). Providing control of wort oxygen concentration and wort composition is adequate (which it should be in the majority of breweries) poor control of pitching rate is the single major contributor to variability in beer quality.

The financial consequences of variable beer quality are difficult, if not impossible, to quantify. The ability to produce a standard product is important where global brands are produced at several different geographical locations. Clearly, variable beer quality may have negative effects in terms of consumer choice and therefore this may be a major factor in determining brand profitability.

#### **3.2 Manpower costs**

Use of an automatic pitching rate control system based on an Aber™ Yeast Monitor would impact on manpower costs since there would be a reduced need for skilled laboratory staff capable of carrying out yeast analyses. It is unlikely that laboratory staff capable of performing these tasks would be entirely eliminated since they would normally also carry out routine microbiological QA tests. Nevertheless, in a medium to large brewery it would be likely that savings equivalent to one person would be feasible, particularly if the Yeast Monitor is multiplexed and also used to control yeast cropping. In the latter case the need for an operator to monitor the yeast, beer interface during cropping would be eliminated. In financial terms this would be equivalent to approximately 40,000 Euros per annum.

There would also be some manpower savings associated with improved fermentation consistency. Thus, it would result in a more predictable process which would reduce the complexity of the logistics operation. This could be viewed as an opportunity to maintain the same beer output with reduced manpower. The magnitude of the potential savings are difficult to quantify, nevertheless assuming manpower costs of 4.4 Euros per hl it follows that in a one million hl brewery every 1% reduction in manpower costs would attract savings of 44,000 Euros per annum.

### 3.3 Fermentation efficiency

Fermentation efficiency, as measured in terms of ethanol yield, is defined by three inter-related factors. These are the initial wort concentration, the specific gravity of the resultant beer and the ethanol concentration of the beer. In a high gravity lager fermentation using an all-malt 15° Plato wort, a typical pitching rate would be *ca.* 15 million cells / ml. In weight terms this equates to approximately 4g/l wet weight. In a well-controlled efficient fermentation the yeast undergoes 2 to 3 doublings giving a terminal yeast count of *ca.* 80 million cells / ml (*ca.* 20g/l wet weight).

Good control of fermentation is essential in order to ensure that the desired relation is maintained between the initial concentration of sugar in the wort and the final ethanol concentration in the beer. Failure to control the extent of yeast growth during fermentation will change the relation between the quantity of extract used for new biomass formation and that which is converted into ethanol. Yeast growth extent is regulated by wort composition and a combination of the initial pitching rate and the dissolved oxygen concentration. In practice, the effect of wort composition can be discounted since when fermentation commences there is no opportunity to change it. It follows therefore that for any given wort the extent of yeast growth is controlled by the choice of pitching rate and the availability of oxygen. Oxygen is required primarily for the synthesis of sterols and unsaturated fatty acids. These lipids, which are essential for cell membrane structure and function, are formed during the aerobic phase of fermentation. During the anaerobic phase the pre-formed lipid pool is diluted as a consequence of cell proliferation.

In the majority of fermentations sterol and unsaturated fatty acid depletion is the cause of yeast cell proliferation depletion. The quantity of sterol and unsaturated fatty acid formed by each yeast cell during the aerobic phase of fermentation is governed by both the pitching rate and the wort dissolved oxygen concentration. In other words, the extent of yeast growth during fermentation is regulated by the quantity of oxygen supplied to each yeast cell. It follows that for any given dissolved oxygen concentration, yeast growth is controlled by the pitching rate. This is illustrated in Figure 2.

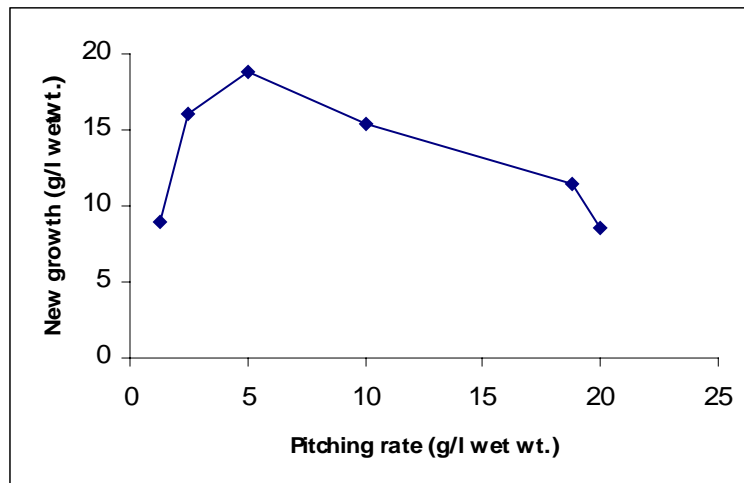


Figure 2. Effect of varying pitching rate on yeast growth (total crop - total yeast pitched) for an all-malt 15° Plato oxygen saturated wort. The target pitching rate for this fermentation would be *ca.* 2.5 - 3.0 g/l wet wt.

Yeast growth was less at the extremes of pitching rate. It may be thought therefore, that in terms of fermentation efficiency, it would be beneficial to use either a very high or a very low pitching rate. In practice this benefit is largely illusory. Figure 3 shows the individual attenuation profiles observed at each pitching rate.

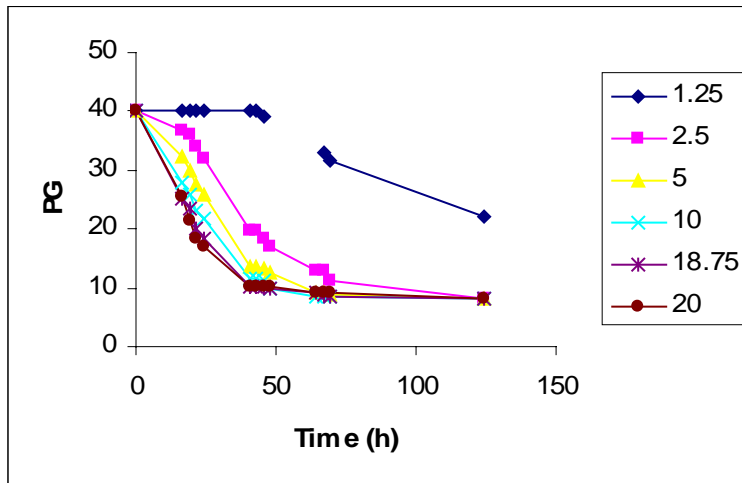


Figure 3. Attenuation profiles obtained at each pitching rate for fermentations described in Figure 2.

At very low pitching rates the wort failed to attenuate within a practical time span. Therefore, there would be no practical benefit in using a very low pitching rate. At very high pitching rates yeast growth extent is low and fermentation rate is very rapid (figures 2,3). This is advantageous in terms of overall efficiency, however, these conditions produce unacceptable changes in the concentrations of important flavour components such as esters (Figure 4).

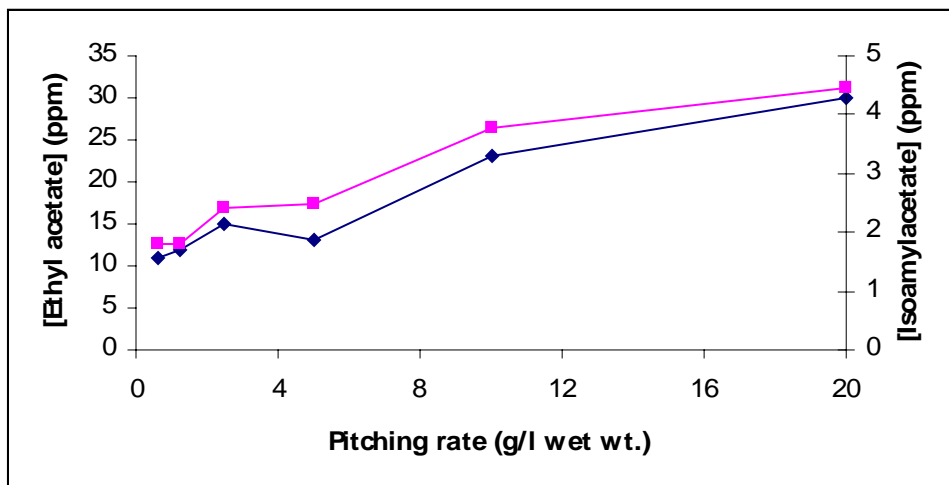


Figure 4. Effect of pitching rate on the formation of two esters during the fermentation of an oxygen saturated all-malt 15°P lager wort.

Both ethyl acetate and isoamyl acetate are important flavour compounds produced by yeast during fermentation. Both have low flavour thresholds and it is essential that they are produced at the concentration desired to meet the specification for the particular beer under consideration. The relatively high ester levels associated with high pitching rates would render the beers unacceptable.

Nevertheless, there was a correlation between yeast growth and ethanol yield (Figure 5).

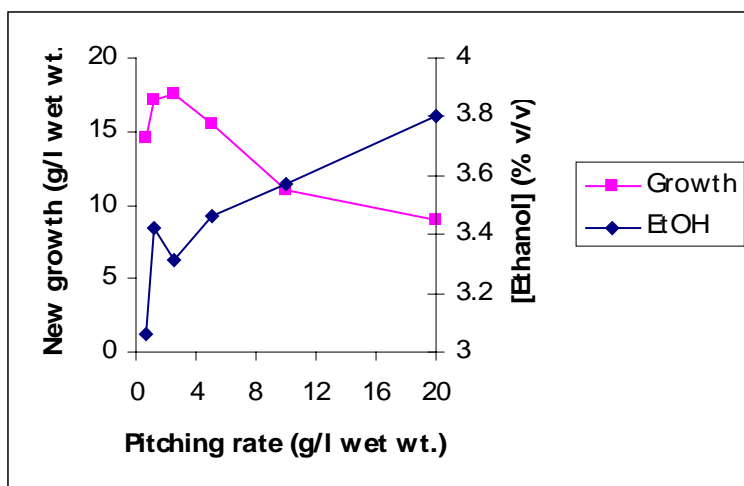


Figure 5. Effect of varying pitching rate on yeast growth and ethanol yield during fermentation of an oxygen saturated all-malt 15°P lager wort.

As indicated, ethanol yield was relatively low at the lower yeast pitching rates. This was a consequence of the failure of the wort to become fully attenuated (cf Figure 3). At medium to higher pitching rates, as predicted, there was an inverse correlation between the extent of yeast growth and ethanol formation. It would not be possible, for the reasons given already, to take advantage of the elevated ethanol yields at very high pitching rates. Nevertheless, within the range of pitching rates used for this type of fermentation (2.5 - 3.0 g/l wet wt. yeast) it can be seen that errors in pitching rate control would potentially result in variable yields of ethanol and hence, variable fermentation efficiency.

The financial implications of excessive yeast growth can be illustrated by the following example. In a high gravity fermentation using 1600hl of an all-malt wort with an initial concentration of 15°P the expected yield of ethanol would be *ca.* 6.7% v/v. If the yield of ethanol was reduced by 0.1% v/v as a result of poor control of pitching rate the overall yield of beer, after dilution to 4.1% would be reduced by:

$$\frac{1600 \times 6.7}{4.1} - \frac{1600 \times 6.6}{4.1} = 39\text{hl}$$

In order to generate 1 million hl of beer at high gravity it would be necessary to perform 625 x 1600hl fermentations. If this loss rate was applied to half this number of fermentations the lost volume of diluted beer would amount to (39 x 312) = 12,168hl of beer. There would be no decrease in the usage of raw materials and the operating costs of managing fermentations would be unchanged. Assuming a production cost for the beer of 13 Euros per hl, the financial penalty of fermentation inefficiency would be equivalent to 158,184 Euros.

### 3.4 Financial considerations for new breweries or increased fermentation capacity

Poor pitching rate control has the potential to produce variable fermentation cycle times and rates. A good example of the impact of using the Yeast Monitor to control pitching rate is shown in Figure 6. In this case the brewery in Japan (11) has switched from a traditional off-line cell counting method to using the on-line Yeast Monitor for pitching the correct amount of live yeast and achieved a much more consistent fermentation rate.

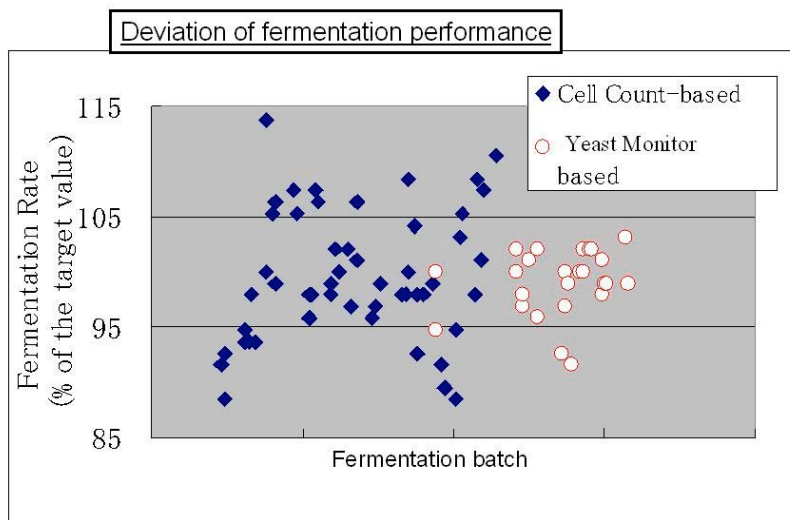


Figure 6. A comparison of the fermentation rates using traditional cell counting and the Yeast Monitor

One of the consequences of variable fermentation rate is that it is not possible to produce an accurate forward plan. The financial consequences of this are usually expressed in terms of capital avoidance. Since it is not possible to forecast with any accuracy when fermentations will end it is necessary to have a certain number of surplus vessels in order to ensure that empty and clean fermenters will always be available for use when required.

Experience suggests that with a poorly controlled fermentation process cycle times would be likely to vary between +/- 3 days of the target. A large element of this inconsistency can be attributed to variability in pitching rate control where traditional methods of control are used (with the caveat that other sources of inconsistency would also be contributory factors).

The capital cost of a typical modern cylindroconical fermenter is approximately 700,000 Euros. If a new brewery is being constructed or additional fermenters are being installed in an existing plant to extend fermentation capacity the opportunity to reduce the total vessel count would attract significant cost savings.

#### 4 Conclusions

The fermentation stage of brewing has a critical impact on the outcome of the whole of the brewing process. With the advent of global brands, produced using very large batch sizes, precise control of fermentation is of fundamental importance for maintaining high process efficiency and high quality consistent product. Of all fermentation variables yeast pitching rate and initial wort dissolved oxygen concentration have pivotal roles in determining the outcome of the process. Precise control of these variables is an essential prerequisite for good control of fermentation. It has been demonstrated here that failure to exert precise control over these variables has the potential to inflict severe financial penalties on the operation of the brewery. The Aber™ Yeast Monitor provides a cost effective route for the automatic control of yeast pitching rate. Precision and repeatability of such control systems are superior to those based on more traditional methods for quantifying viable yeast concentration.

#### 5. References

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