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Are Craft Brewers Underaerating Their Wort?

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ABSTRACT

Small-scale microbreweries and brewpubs often lack some of the expensive equipment essential for maintaining strict consistency in fermentation products. One control that is commonly overlooked is the amount of dissolved oxygen (DO) in wort prefermentation. This leads to the question, are craft brewers underaerating their wort? An investigation is described here that explores the adequacy of current DO levels in craft breweries and whether this has any correlation with fermentation issues such as long lag time and slow fermentation. The range of oxygenation levels with respect to their effects on fermentation speed and the variance in DO requirements between laboratory-grown cultures and multiple-generation brewery cultures are also addressed. The DO levels of wort from a small sampling of mid-sized craft breweries were compared with the same wort at a measured 10 ppm DO in lab-scale fermentation trials. A commercial ale yeast strain was used for all fermentations, and fermentation vessels were kept at a constant temperature in a glycol-controlled water bath. The study was designed to determine whether craft breweries are sufficiently oxygenating their wort and the impact of this on yeast performance, as well as to provide a possible approach to improve fermentation success.

Keywords: aeration, dissolved oxygen, slow fermentation, underattenuation

SÍNTESIS

A las cervecerías artesanales frecuentemente les faltan algunos de los equipos costosos esenciales para mantener una uniformidad estricta en sus productos. Un control que por lo general se desdeña es el control de la cantidad de oxígeno disuelto (DO) en la prefermentación del mosto, lo que podría conducir a que los cerveceros artesanales no airean suficientemente al mosto enfriado. Se estudiaron los niveles de DO en los mostos de cervecería artesanales para tratar de determinar si esto tendría alguna correlación con problemas tales como un lento arranque de la fermentación y/o fermentaciones lentas. También se estudió el efecto del nivel de oxígeno sobre la velocidad de la fermentación, así como la diferencia en los requerimientos de DO de cultivos propagados en el laboratorio y aquellas levaduras provenientes de fermentaciones anteriores. Los niveles de DO en mostos de un pequeño número de cervecerías artesanales de tamaño medio fueron comparados en fermentaciones en laboratorio con un mosto con 10 ppm DO, usando una sepa de levadura comercial tipo "ale" en mini fermentadores mantenidos a temperatura constante en baño de maría con glicol. Con esto se quiso ver si cervecerías artesanales oxigenaban suficientemente a sus mostos y como esto afectaba el desempeño de la levadura, como también proveer una manera de mejorar la fermentación.

Palabras claves: aeración, atenuación pobre, fermentación lenta, oxígeno disuelto

Introduction

Proper levels of oxygen are necessary for optimal yeast performance during the early stages of wort fermentation, because oxygen plays an integral role in promoting lipid synthesis for cell wall production (2). Without an adequate supply of oxygen as a building block, yeast cells characteristically display low viability and poor performance in fermentation (3). Recommended levels of oxygenation are in the range of 8 to 10 ppm (2,5); however, many craft breweries depend on existing protocols for aeration that do not involve measurements and may not be optimal. Suboptimal oxygenation may be the cause of many common fermentation problems, leading to longer fermentation times and underattenuated beers.

Neva Parker has been with White Labs since 2002. She earned her B.S. degree in microbiology from Gonzaga University in Spokane, WA, and first became interested in the brewing industry while studying abroad in London. Parker currently manages laboratory operations and has been responsible for the development of new products and services, as well as researching the effects of various brewing aspects on yeast performance, using lab-scale fermentation trials. She has presented at several workshops and conferences and has published articles in brewing magazines. She has been an ASBC member since 2003.

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Materials and Methods

The investigation involved a total of 12 San Diego craft breweries. Postoxygenated wort samples were collected from each brewery in two sterile, 2-L fermentation bottles fitted with a sterile silicone stopper and stainless-steel dip tube for liquid transfers. Bottles were filled from the bottom, using the dip tube to prevent any additional uptake or loss of oxygen. The wort dissolved oxygen (DO) levels were measured postoxygenation and cooling through a heat exchanger, using an oxygen analyzer (InTap 4000 e, Mettler-Toledo). When current DO levels were below 10 ppm, pure oxygen was added to one of the two fermentation bottles, using a DO stone with a filter in a closed environment to achieve the recommended levels. The fermentation performance of the normal and oxygen-enhanced worts was then compared.

A standard commercial brewery wort at 12°P was also used to conduct fermentation trials to determine whether oxygen depletion of earlier generations would affect the performance of later generations of yeast. These fermentations were maintained at less than 6 ppm DO for each successive generation. In addition, a trial was conducted to determine what effects higher than recommended DO levels would have on fermentation performance. A comparison was done between worts with 5.48, 10.15, and 19.15 ppm DO.

Table 1. Summary of craft brewery oxygen delivery and dissolved oxygen (DO) levels

Brewery	Brewery flow rate (L/min)	Length of time in-line	Original gravity (°P)	Final gravity (°P)	Actual DO (ppm)
1	6	40 min for 40 bbl	12.5	2.3	5
2	7	30–40 min for 10 bbl	12	1.8	8.25
3	7	20 min for 8 bbl	12.8	3.3	9
4	12	75–80 min for 15 bbl	25.5	4.1	5.5
5	6	25–30 min for 10 bbl	12.8	3.2	35.8
6	5	90 min for 15 bbl	12.7	3.2	24.4
7	7	40 min for 40 bbl	12.3	2.2	6.2
8	6	30 min for 10 bbl	14.4	2.3	8.1
9	6	45 min for 15 bbl	13.2	3.3	5.42
10	7	35 min for 10 bbl	12.5	2.4	7.2
11	7	40 min for 15 bbl	12.7	2.2	6.54
12	6	35 min for 10 bbl	12.3	2.3	5.85

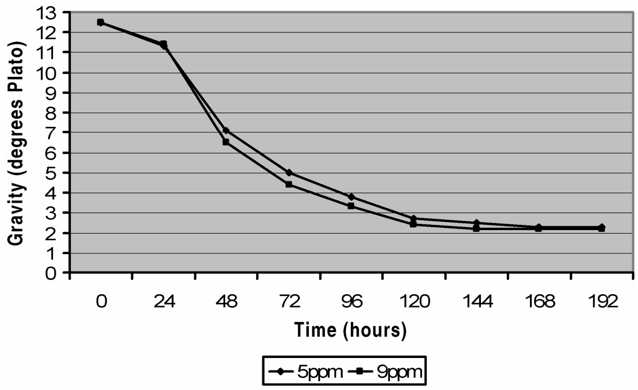

Figure 1. Fermentation speed of one brewery's current wort (5 ppm) versus oxygen-enhanced (9 ppm) wort.

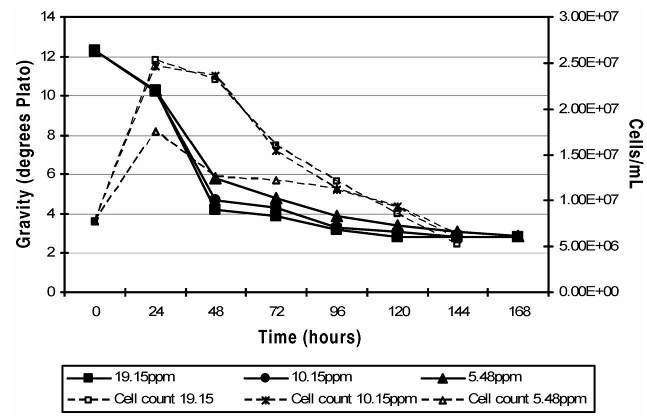

Figure 2. Fermentation speed and yeast cell counts for wort with varying dissolved oxygen levels.

A commercial ale yeast strain was used in all trials, and the fermentations were carried out in a temperature-controlled environment using a glycol-chilled water bath. Yeast was pitched at a rate of 0.75 million cells/mL/°P. The fermentation temperature remained constant at 68°F (20°C).

Fermentation vessels were sampled every 12 h. Gravity (degrees Plato) was measured using a handheld density meter (DMA3500, Anton-Paar), and real attenuation was measured using an alcolyzer (Anton-Paar) plus beer. The cell count of yeast in suspension, original yeast viability, and cell budding percentage were obtained using the ASBC methylene blue staining procedure (1).

Results and Discussion

A large variation was observed among the local craft brewers. Some breweries were underaerating, while others were aerating at much higher levels than the recommended 8–10 ppm (Table 1). More than 50% of breweries had a measured DO level of less than 8 ppm. Most brewers were using a flow meter to introduce pure oxygen in-line and estimating their expected DO level based on their wort fill time. None of the breweries measured the actual DO in their wort prefermentation.

In each case, the results of the fermentation trials determined that increased DO levels caused an increase in fermentation speed. Fermentations with higher DO levels were able to finish fermentation faster, typically 24–48 h earlier, than the control fermentations (Fig. 1). In a few cases, the trials with the enhanced DO levels were able to achieve higher attenuation percentages (average 72.4%) than their respective control fermentations (average 69.6%); the mean difference for the trials overall was 2.8%.

Table 2. Yeast budding percentage during fermentation with varying dissolved oxygen (DO) levels

Time (h)	Budding percentage		
	19.15 ppm DO	10.15 ppm DO	5.48 ppm DO
0	30.0	30.0	30.0
12	74.3	62.8	54.2
24	70.6	58.1	51.4
36	53.1	44.5	48.1
48	26.9	31.0	36.8
60	27.2	24.4	24.6
72	26.8	20.7	15.0
84	24.5	20.3	14.6
96	22.2	19.4	14.1
120	12.0	12.6	11.2
144	9.2	9.4	5.4

Figure 2 displays the fermentation speed and related yeast cell counts for fermentations in the same wort with varying DO levels. The fermentations with 19.15 and 10.15 ppm DO displayed similar fermentation performance and yeast count. The control wort, at 5.48 ppm, displayed a significantly slower fermentation speed and lower cell count throughout the fermentation. Both of the oxygen-enhanced fermentations displayed significantly higher budding percentages than the control fermentation (Table 2), resulting in higher final cell mass.

Figure 3 shows the fermentation performance for yeast that had undergone multiple generations and been undersupplied with

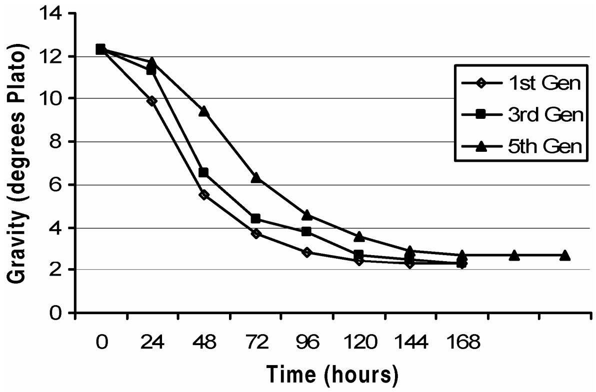

Figure 3. Fermentation performance of worts using multiple generations of yeast with depleted oxygen resources.

oxygen (5–6 ppm) during each generation. The fifth-generation yeast fermentation displayed a significant increase in lag time and time to complete fermentation. In addition, the expected terminal gravity was not reached compared to the fermentations with earlier yeast generations.

Conclusions

It is widely known that oxygenation of wort provides essential cofactors for lipid synthesis in growing yeast cells. Without adequate oxygen, yeast cells become weak, more susceptible to stress, and less able to carry out a fermentation in which conditions are unfavorable.

The findings of this study clearly show that an increase in available oxygen in the wort results in a higher budding percentage and, therefore, higher cell growth. The control fermentations, with no oxygen added, never reached the yeast cell mass that was obtained in the oxygen-enhanced fermentations. As shown in Figure 2, the fermentation with inadequate DO never reached the cell mass of the other fermentations. This is particularly important to brewers during yeast harvest, because insufficient oxygen supply in the initial generation may result in not enough yeast being produced to collect for subsequent fermentations. In each trial, the oxygen-enhanced fermentations also reached terminal gravity faster than the controls, and 3 of the 12 worts sampled also reached a lower terminal gravity.

Most significant were the long-term effects of reduced oxygen levels on multiple yeast generations. When the yeast was deprived of sufficient oxygen early on, it resulted in the proliferation of fewer cells that were able to perform sufficiently in later generations, which was most notable after the third generation. The data suggest that these yeast cells did not have ample resources to build solid cell walls, resulting in fewer cells with glycogen reserves and membranes that could withstand the stress of fermentation and the alcoholic, low-pH environment of beer (4).

The goal was to determine whether common fermentation issues that small breweries experience are related to inadequate DO, since most do not have the means to take measurements. According to the results, insufficient oxygen levels resulted in increased lag time and higher final gravity compared with fermentations using the same wort with enhanced oxygen levels. This lack of proper oxygenation can lead not only to problems in the immediate fermentation, but can be carried forward to significantly reduce the performance of yeast in successive fermentations. Measurement of DO levels can be a very important tool for brewers who are experiencing similar problems, because it can give some indication as to the effectiveness of their current brewing practices.

Some topics for future investigations would be at what level DO in wort would have a toxic affect on yeast and fermentation, the effect of varying oxygen levels on high cell-density fermentations, and how increasing DO levels in wort may affect final beer flavor and stability.

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