Effectiveness of Various Methods of Wort Aeration

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ABSTRACT

Various methods of wort aeration were tested for their ability to dissolve oxygen in water. Boiled and cooled water was aerated using pumped air at 99 mL/min and 1009 mL/min, with and without the use of an aeration stone, and the dissolved oxygen content was measured for up to 90 minutes of aeration. In addition, rocking/shacking the fermentor was tested as another commonly used method of wort aeration. Results: Boiled and cooled water contained a significant amount of dissolved oxygen after it was delivered to the fermentor even before active aeration was initiated. Rocking/shaking the fermentor was the quickest method of saturating the water with oxygen. Pumping air at the high flow rate using an aeration stone was also effective. Pumping air without the aeration stone required significantly longer time to dissolve oxygen. Pumping air at the low flow rate, similar to the flow rate produced by an inexpensive aquarium pump, was slow to dissolve oxygen. Conclusion: Oxygen can be quickly dissolved into wort from the headspace of the fermentor with rocking/shaking. Wort may also be effectively aerated in a reasonably short time by pumping air into it with an aeration stone, but only if the airflow rate is relatively high. Pumping air at lower flow rates can be effective if performed over a long period of time.

INTRODUCTION

It is generally agreed that a significant amount of yeast growth is important for producing beer with the appropriate level of attenuation and with the appropriate flavor profile. It is also generally agreed that the oxygen content of the wort early in the fermentation is important to enable this desired yeast growth. Various methods of wort aeration have been touted as either good or poor methods for entraining air into the wort, but the data supporting such claims is difficult to find in resources readily available to most homebrewers. The purpose of the current study was to test the efficacy of various methods of aeration commonly used by homebrewers to dissolve oxygen in wort.

METHODS

Preparation of Oxygen-poor Water

In all experiments, the method of aeration was tested using tap water. Approximately six gallons of tap water was boiled for several minutes, and five gallons of the boiled water was transferred to either ~5.2-gallon capacity glass carboy fermentor or a 6.5-gallon capacity polyethylene bucket fermentor equipped with a gasketed lid. The water was cooled by pumping boiled water through a convoluted copper counter-flow chiller, which was chilled with flowing tap water. The pump used was a Masterflex peristaltic pump equipped with two Masterflex L/S 18 standard pump heads and silicone tubing. Quick disconnect fittings or barbed fittings were used for all tubing connections. The temperature of the cooled water entering the fermentor ranged from 21.5 °C to 24.2 °C in the various experiments, and the exact temperature of the water was recorded for each aeration experiment. In experiments using the glass carboy fermentor, the cooled water was allowed to fall through the air from the outlet tubing located within the neck of the carboy. In the experiment using the plastic bucket fermentor, the outlet tubing was placed at the bottom of the fermentor to minimize splashing prior to active aeration.

Aeration Methods

The aeration methods tested in the current study all utilized ambient air as the source of oxygen. Cooled water in the fermentor was aerated by one of the following methods for each experiment. In some experiments room air was pumped into the water in the glass carboy fermentor using a peristaltic pump (Masterflex) and silicone tubing either at the rate of 99 mL/min or at the rate of 1009 mL/min, depending upon the experiment. Airflow rates delivered by the pump were determined empirically by measuring the time required to displace 984 mL water contained in a canning jar submerged in water with the stainless steel aeration stone in place. The lower airflow rate was set to be similar to the rate delivered by an inexpensive aquarium pump. The high flow rate was the maximum flow rate that could be delivered by this particular pump/pump head combination.

Air exiting the pump passed through an in-line, 50 mm Millex-FA filter (Millipore) as would be used during typical wort aeration to minimize microbial contamination. The outlet of the filter was connected to a polycarbonate racking tubing of sufficient length to deliver air to the bottom of the fermentor, allowing bubbles to rise through the height of the liquid in the fermentor. In some experiments, a stainless steel aeration stone with 2 μM pore size was placed at the outlet of the racking tubing. In other experiments, no aeration stone was used. Water in the carboy was aerated continuously for up to 90 minutes, and the dissolved oxygen content of the water was measured every 5 minutes during aeration.

In one experiment using the plastic bucket fermentor, after the cooled water was delivered to the bucket, the bucket was sealed with its lid and the water in the bucket was mixed vigorously by holding the bucket at the top, tilting the bucket on its bottom edge, and rocking the bucket back and forth at the rate of approximately two times per second. After two minutes of rocking/shaking, the bucket was opened and the dissolved oxygen content was measured and recorded. Measurement of dissolved oxygen required one minute of time. The bucket was then resealed with the lid, and aeration by rocking/shaking was continued until a total 5 minutes had elapsed since beginning aeration (2 minutes since resealing the bucket), at which time the bucket was opened, and the dissolved oxygen content was measured and recorded. This process was continued for a total of 20 minutes, measuring the dissolved oxygen content every 5 minutes.

Measurement of Dissolved Oxygen

Dissolved oxygen content of the cooled water was measured using a Yellow Springs Instruments (YSI) Model 57 dissolved oxygen meter equipped with a YSI Model 5739 probe, calibrated with water-saturated air, prior to each set of experiments. The temperature of the cooled water was measured throughout the aeration time and was determined to not vary more than 0.5° C from the beginning to the end of each aeration experiment. Dissolved oxygen content of water at saturation was calculated using the water temperature and atmospheric pressure for each experiment, and the instrument was calibrated accordingly for each experiment. To facilitate comparison between experiments, the dissolved oxygen content of the water for each experiment was expressed in terms of percent saturation.

RESULTS

The dissolved oxygen of water aerated by the various methods tested is shown in Figure 1.

In all experiments, the dissolved oxygen content of the water immediately after it was delivered to the ferment was significant. In experiments in which the cooled water was allowed to fall through the air to the bottom of the glass carboy, the dissolved oxygen content ranged from 55% to 65% of saturation levels. Even when splashing was minimized by allowing the water to flow into the bottom of the plastic fermentor bucket, the dissolved oxygen content was significant (43% of saturation) prior to any active attempt to aerate the water.

Dissolving oxygen in cooled water by pumping air at the low flow rate without an aeration stone was relatively slow, rising to only 59% saturation after 15 minutes and to only 74% saturation after 90 minutes. Using the aeration stone with the low airflow rate improved the oxygenation rate only slightly, with dissolved oxygen reaching 63% saturation after 15 minutes and 79% saturation after 90 minutes.

Some improvement in oxygenation was seen using the higher airflow rate. Without the aeration stone, 64% saturation was achieved in 15 minutes and 90% saturation was achieved in 90 minutes. Addition of the aeration stone to the high airflow rate substantially improved the rate of oxygenation, reaching 90% saturation in approximately 20 minutes.

The most rapid method of oxygenating the water was achieved by the rocking/shaking method, in which over 90% saturation was achieved in less than 5 minutes of aeration.

DISCUSSION

The purpose of these experiments was to evaluate the effectiveness of different methods of aerating wort for beer production. However, these experiments were conducted using water rather than wort, solely because of the significantly greater expense of using wort. The solubility of oxygen in a 12 °Plato wort is about 15-25% less than in water, depending upon the temperature.[i] It is unlikely that this difference in oxygen solubility would significantly affect the conclusions about the aeration methods themselves. An important exception is that foam produced by aerating wort, which is absent when using water, may fill the headspace of the fermentor, requiring aeration to be interrupted to allow the foam to collapse before continuing aeration, especially when pumping air at a high flow rate.

The data from these experiments indicate that rocking/shaking the plastic bucket fermentor is a highly effective and quick method of dissolving oxygen in the wort. However, if a glass carboy were to be used as a fermentor, the rocking/shaking method is probably more difficult to perform properly and could be somewhat dangerous. These data also indicate that aeration by pumping air through a 2 μm pore aeration stone at approximately 1 liter per minute is also an effective and relatively quick method of dissolving oxygen. The type of pump used in the current study may also be used to transfer wort from lauter tun to boil kettle, boil kettle to fermentor, and to deliver sparge water to the lauter tun. Other types of pumps delivering similar flow rates would be expected to be as effective, so no additional expense would be required if the brewer is already using such a pump in the brew house.

The methods using low airflow rates were slow to oxygenate the wort. It is not known how representative the airflow rate used in this study (99 mL/min) is of other aquarium pumps that could be easily acquired. It is clear, however, that the flow rate delivered by the pump, especially when an aeration stone is used, is a major factor in how quickly the wort will be oxygenated, and the brewer should consider the delivery rate of the pump when considering this method of wort aeration.

The methods tested in this study were chosen to minimize the risk of microbial contamination. Accordingly, other methods that expose wort to open air for an extended time, such as by repeated pouring between containers or using stirring devices in an open container, were not evaluated in this study, although they may be quite effective. Other methods of aerating wort that were not tested in the current experiments are those that allow air to be pulled into the wort through very small openings in the line on the low pressure side of the pump. Such methods, especially if the air entering can be filtered to minimize microbial contamination, deserve some experimental testing and could at a minimum reduce the time required to aerate in the fermentor.

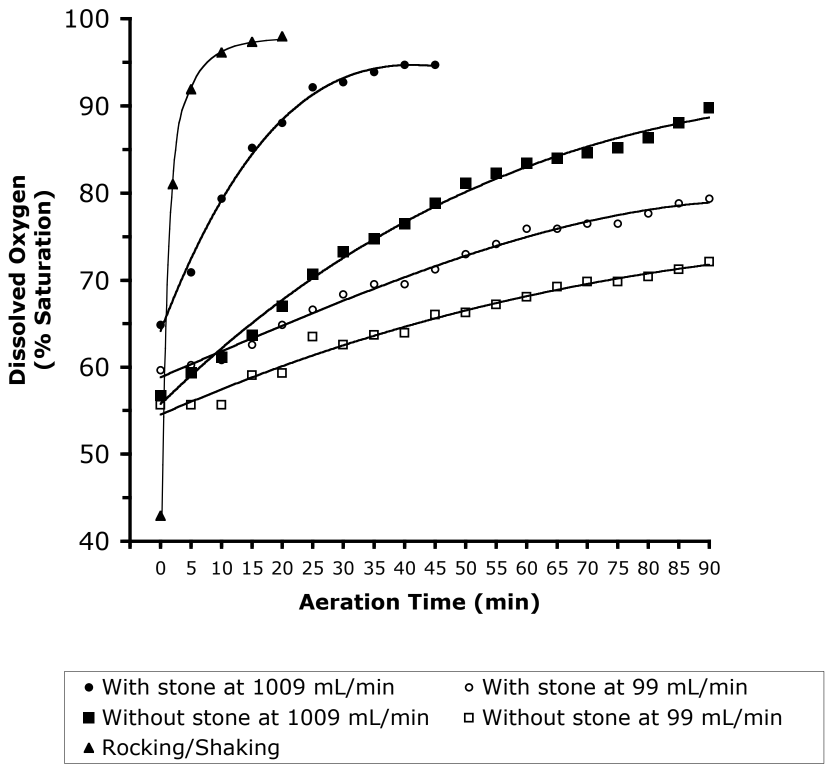
The infusion of pressurized pure oxygen into wort is undoubtedly another effective means of raising the wort oxygen content. However, there are added costs associated with the use of pure oxygen, and there is some risk of toxicity to the yeast from over-oxygenating wort. Saturating wort with pure oxygen is likely to be toxic to the yeast. Thus, some means of monitoring the oxygen content of the wort or of controlling the amount of oxygen delivered to the wort would appear to be necessary. Testing the relative effectiveness of aerating with air versus pure oxygen would be a reasonable and useful addition to experiments presented here.

The current study was also significantly limited in that each aeration method was tested only once. (A second unreported experiment was conducted using the rocking/shaking method that confirmed that the rapid oxygenation rate observed in the first experiment was not merely the result of some gross error.) Accordingly, the variability of each method is unknown at this time. A likely source of variability in the results could be expected from variability in the air pumping rate, which was demonstrated to significantly affect the oxygenation rate. Also, there was significant variability in the oxygen content of the water immediately after delivering it to the fermentor. This variability is undoubtedly due to the uncontrolled manner in which the water was delivered to the fermentors. It is also possible that air is pulled into the water at the numerous tubing connections to equipment located between the boil kettle and the fermentor. It is quite likely that the exposure of the water to air sitting in the fermentor accounts for a significant portion of the oxygen dissolved in water within the fermentor.

The potentially high oxygen content of wort entering the fermentor must be considered in experiments intended to test the efficacy of alternatives to wort aeration/oxygenation. For example, a recent unpublished but widely disseminated report by Hull from New Belgium Brewing Company concluded that the addition of a very small amount of olive oil to yeast prior to pitching into unaerated wort resulted in fermentations that were consistent, complete, and with acceptable flavor quality compared to standard, aerated worts. The conclusion was that olive oil addition might be substituted for wort aeration. However, the dissolved oxygen content of the wort in Hull's studies was not measured, and it seems quite possible that the worts in Hull's experiments actually contained substantial oxygen content, sufficient for the yeast to grow adequately to complete the fermentation without any other additions. Unfortunately, Hull did not perform a controlled fermentation without any other additions.

In conclusion, the homebrewer has at least a couple of inexpensive means of aerating wort that minimizes microbial contamination and that can dissolve substantial amounts of oxygen in the wort. Rocking/shaking a plastic bucket fermentor is very effective and requires the minimum amount of time. Pumping filtered air with an aeration stone at relatively high flow rates is equally effective and requires relatively little time, especially if an aeration stone is used. Pumping air at low flow rates will ultimately dissolve the same amount of oxygen in the wort but will require a significantly longer time.

Figure 1: Dissolved oxygen content of water during aeration by various methods



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