Control of Dissolved Gases in the Brewery using a Hydrophobic Membrane

By Jon W. Brown¹, R. Bowerman¹ and D. Smith²


1999 EBC Poster.

ABSTRACT

Gases in contact with liquids will partition between gaseous and dissolved phases, the concentration in the liquid being determined by the partial pressure of each gas in the gaseous phase (Henry's Law).

Hydrophobic membranes allow highly intimate contact between the two phases allowing equilibration to be achieved very rapidly. Data will be presented for a brewery-sized (3-400 hl/hr) unit where gases of interest to brewers have been controlled in-line by the use of a hydrophobic membrane and appropriate control system. In particular the contents in beer of oxygen, nitrogen, and carbon dioxide can all be increased or decreased in a controlled manner.

Keywords: Hydrophobic Membrane, Dissolved Gases Control, Deoxygenation, Nitrogenation, Denitrogenation

SINTÉSIS

Los gases con líquidos se dividirán entre fases gaseosas y disueltas, la concentración en el líquido será determinada por la presión parcial de cada gas en la fase gaseosa (Ley de Henry).

Las membranas hidrofóbicas permiten un contacto muy íntimo entre las dos fases lo que permite que se equilibren muy rápidamente. Se presentará información de una unidad del tamaño de una para una cervecería (3-400 hl/hr) donde los gases de interés para los cerveceros han sido controlados en línea mediante el uso de una membrana hidrofóbica y un sistema de control adecuado. En particular los contenidos de oxígeno, nitrógeno y dióxido de carbono pueden ser aumentados o disminuidos de una manera controlada.

INTRODUCTION

The control of dissolved gases in the brewery is very important for the final presentation of beer to the consumer. Carbon dioxide and nitrogen levels will directly affect the foam presentation in terms of head size, head appearance and lacing as well as the sparkle of beer. Carbon dioxide has a direct impact on beer flavour. Nitrogen has an indirect effect, as it is flavourless itself, but its presence affects flavour. The absence of oxygen is important for producing a beer of good flavour stability.

Traditional methods of gas control are good at raising concentrations, typically by injection and dissolution (though this is not always well controlled) followed by analysis and feedback control of the injector. Gas removal is, however, much more problematic and no well controlled methods are readily available.

HYDROPHOBIC MEMBRANE

Principle

The concentration of gas dissolved in a liquid is proportional to the partial pressure of that gas in contact with the liquid when the two phases have been allowed to come to equilibrium (Henry’s Law).

Formally - at equilibrium

\[ P_B = Z_B K_B \]

\[ P_B \] = partial pressure of gas B

\[ Z_B \] = mole fraction of gas B in solution

\[ K_B \] = Constant for gas
Thus by controlling the composition and total pressure (and hence all partial pressures) of the gaseous state, all the dissolved gas concentrations can be controlled.

The practical constraint on the use of this principle is the speed at which equilibrium can be achieved. For gas top pressure on a beer vessel this will be of the order of days, even for beer in a keg, equilibrium is not reached within a week.

The hydrophobic membrane provides a method of greatly accelerating the equilibration process, to the extent that it can be driven substantially towards equilibrium, in-line, at standard brewery flow-rates. The actual rate of gas transfer is dependent upon the beer flow and the partial pressure differential from equilibrium.

Construction
The membrane is a bundle of highly porous hollow fibres with a total surface area of 135 m$^2$. The beer flows around this bundle and thus has a very high contact area (see Figure 1). The membrane material provides a hydrophobic barrier which allows the gas to diffuse either into or out of the liquid depending on the pressure conditions. Because of the highly intimate contact between gas and liquid, the gas goes immediately into solution as it would through a surface rather than via bubbles which can take a significant time to dissolve fully.

FIGURE 1
Schematic diagram of membrane.

Brewery Unit
Figure 2 shows a brewery unit, the beer is delivered to the bottom of the membrane and gas applied to the top. The gas pressure is controlled by a feedback system which uses in-line analysis of the beer exiting the membrane.

FIGURE 2
(above and below)
Brewery Installation.
**OPERATIONAL MODES**

**Sweep**

When removing oxygen from beer, the target is zero. In order to minimize oxygen in beer, a sweep of gas is run on the gas side. This is necessary in order to sweep away diffused oxygen which would otherwise rapidly come to equilibrium with the incoming beer oxygen concentration and prevent further removal. The sweep rate will determine the oxygen concentration on the gas side for a given flow rate and dissolved oxygen (d.o.) content on the liquid side, and hence can determine the overall oxygen reduction.

The application below shows removal of oxygen with either carbonation or decarbonation to target (Table 1).

**TABLE 1**

<table>
<thead>
<tr>
<th>O₂ in ppb</th>
<th>O₂ out ppb</th>
<th>CO₂ target g/l</th>
<th>CO₂ in g/l</th>
<th>CO₂ out g/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>15</td>
<td>2.25</td>
<td>2.30</td>
<td>2.24</td>
</tr>
<tr>
<td>40</td>
<td>17</td>
<td>2.05</td>
<td>2.30</td>
<td>2.03</td>
</tr>
<tr>
<td>70</td>
<td>25</td>
<td>2.10</td>
<td>2.05</td>
<td>2.09</td>
</tr>
<tr>
<td>70</td>
<td>25</td>
<td>2.20</td>
<td>2.05</td>
<td>2.20</td>
</tr>
<tr>
<td>120</td>
<td>54</td>
<td>5.10</td>
<td>4.90</td>
<td>5.10</td>
</tr>
<tr>
<td>120</td>
<td>51</td>
<td>4.20</td>
<td>4.20</td>
<td>4.15</td>
</tr>
<tr>
<td>320</td>
<td>51</td>
<td>4.20</td>
<td>4.20</td>
<td>4.15</td>
</tr>
<tr>
<td>1000</td>
<td>340</td>
<td>2.00</td>
<td>2.80</td>
<td>1.97</td>
</tr>
</tbody>
</table>

Flow rates were in the range 200 - 300 hl/h for these results. Sweep rates are balanced between the need for oxygen removal and the cost of CO₂. Where product is being decarbonated, part of the sweep is made up of the CO₂ being removed from the beer. As a rough indication, removal of 0.1 g/l CO₂ from the beer at 300 hl/h results in an increase to the sweep gas of 1.5 m³/h.

Figure 3 shows that for a given sweep rate, oxygen reduction can be achieved across a range of concentrations. In this case 60% or better reduction (as shown by the line) was achieved at a nominal 10 m³/h sweep and 250 hl/h beer flow rate.

**Dead End**

In the situation where the gas content needs only to be increased, then a small pressure is applied to the gas side of the membrane.

In the example below, the CO₂ content of the beer was maintained while nitrogen was added at beer flow rates from 50 - 400 hl/h.

Pure nitrogen gas was applied to the gas side. The CO₂ in the beer rapidly equilibrates by a very small quantity diffusing from the beer to the gas side. By varying the nitrogen pressure on the gas side, the nitrogen content of the beer can be increased or decreased. This is controlled by a feedback loop from an in-line nitrogen meter (in our experiments so far this has been achieved manually).

To raise more than one gas at once a mixed gas supply would be required or the use of two membranes in series has been shown to work on the pilot scale.

**CONCLUSION**

Pilot scale work has been successfully scaled up to brewery scale with full gas control being demonstrated at beer flow-rates up to 400 hl/h.

Specific examples include:

- Deoxygenation and decarbonation
- Deoxygenation while maintaining carbonation
- Deoxygenation and carbonation
- Nitrogenation while maintaining carbonation
- Denitrogenation while maintaining carbonation

Greater flexibility in the control of desired and undesired dissolved gases is achieved by using the hydrophobic membrane than with traditional techniques.