A New Analytical Technique for Brewing Analyses -

Application of Acoustic Impedance Attenuation and Velocity Measurements at Ultrasonic Frequencies to Brewing Analyses

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ABSTRACT

Sound velocity has been widely accepted in brewing for measurement of original gravity and alcohol, but can only be used in clear liquids with little suspended material and no bubbles. We have developed a robust, hygienic and cost effective instrument, which extends the measurement to include acoustic impedance and attenuation. This produces a versatile instrument, which can measure the concentration of solute in the presence of solids or bubbles, and of dispersed material in suspension. Examples include the measurement of malt saccharification, fermentation gravity, cell density in concentrated yeast slurries and the detection of powder breakthrough from filters.

Keywords: Acoustic Velocity, Acoustic Impedance, Perlite-Acoustic Properties, Acoustic Attenuation

INTRODUCTION

Instruments incorporating sound velocity measurements have now become widely accepted in brewing plants and laboratories for analysis of original gravity and alcohol in beer. They are used extensively for real time control of beer blending as they are generally robust, hygienic and cost effective. However they are best suited to relatively clear liquids with little suspended material and no gas bubbles.

SINTÉSIS

La velocidad del sonido ha sido bastante aceptada en la elaboración de la cerveza para la medida de la gravedad original y el alcohol, pero solo puede ser usada en líquidos claros con poco material suspendido y sin burbujas. Nosotros hemos desarrollado un instrumento resistente, higiénico y económico que extiende la medida hasta incluir la impedancia y atenuación acústicas. Esto produce un instrumento versátil, que puede medir la concentración del soluto en la presencia de sólidos o burbujas y del material disperso en suspensión. Algunos ejemplos incluyen la medida de la sacarificación de la malta, la gravedad de la fermentación, la densidad de la célula en las lechadas de levadura concentradas y la detección del polvo desprendido de los filtros.

THEORETICAL CONSIDERATIONS

A schematic of the instrument is shown in figure 1.

Measurement of Sample Impedance

The amplitude of the sound pulse reflected from the first interface between the wave guide and the sample can be used as a measure of the acoustic impedance of the sample. The propor-
tion of energy reflected \((R)\) depends on the relative acoustic impedance \((Z)\) of materials \(a\) and \(b\) according to the formula:

\[
R = \frac{(Z_a - Z_b)}{(Z_a + Z_b)}
\]

where the acoustic impedance is defined as the product of the sound velocity \((V)\) and density \((\rho)\): \(Z = V \times \rho\). The amount transmitted is \(T = (1-R)\). The energy received at the transmitter \((A)\) will thus change as the impedance of the sample changes. If a reference sample is used to calibrate the instrument then the ratio of amplitudes can be used to measure the change in impedance as follows:

\[
\frac{A_{\text{sample}}}{A_{\text{reference}}} = \text{Const.} \times f(Z_i, Z_{\text{ref}}) \times \frac{Z_{\text{sample}}}{Z_{\text{reference}}}
\]

**Measurement of Sample Attenuation**

In order to measure sample attenuation, the signal must pass through the sample. This introduces signal losses at the wave guide/sample interface in both directions, and at the reflector/sample interface. However, if we again compare the amplitude of the received signal for the sample to a reference liquid, this difference in attenuation coefficient \((\alpha)\) can be calculated thus:

\[
\alpha = -\frac{1}{2D_s} \times \ln \left( \frac{A_{\text{sample}}}{A_{\text{reference}}} \right)
\]

This formulation in which \(D_s\) is the path length of the samples eliminates the effect of transmission and reflection losses and the effect of changes in acoustic impedance of the sample. The attenuation coefficient is expressed in decibel/meter (dB/m).

**RESULTS AND DISCUSSION**

**Acoustic impedance for malt saccharification, starch slurry and wort sugars**

Acoustic impedance is affected by the sound velocity and density. It can thus be used in circumstances where the velocity changes but cannot be measured because of high acoustic attenuation. Malt saccharification is an example of a process which can be followed using this instrument as the velocity changes due to the conversion of starch to maltose, but the malt solids prevent normal velocity measurements (Table 1).

**TABLE 1**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Impedance ((A_s / A_{\text{water}}))</th>
<th>Attenuation dB.m⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>10% Sucrose</td>
<td>0.90</td>
<td>~0.1</td>
</tr>
<tr>
<td>10% Corn Starch (boiled and cooled)</td>
<td>0.60</td>
<td>3.8</td>
</tr>
<tr>
<td>10% Hydrolysed Starch (α-amylase treated)</td>
<td>0.9</td>
<td>~0.1</td>
</tr>
</tbody>
</table>

At high starch concentrations, the progress of hydrolysis can thus be followed by measuring the impedance changes. The instrument could potentially be used directly in the mash vessel.

Measurement of alpha-amylase (DU) in the laboratory uses starch concentrations of 1.4%. The starch is solubilised by boiling and presents a relatively clean solution. Neither impedance nor attenuation change sufficiently during hydrolysis. However, sound velocity can be easily measured. Figure 2 shows the progress of hydrolysis by alpha-amylase. This could potentially replace the current wet chemistry method and allow automation of the analysis.

**Acoustic impedance for fermentation progress, sugar, and alcohol**

Acoustic impedance is unaffected by the presence of gas bubbles, and can be used where density changes are large, but sound velocity changes little. This instrument can thus provide a cost effective means of following the progress of fermentation in-situ and could be used in the laboratory to provide an automated measurement of wort fermentability (Table 2).

**Acoustic attenuation for measurement of yeast/beer interface**

Acoustic attenuation can be used to measure the concentration of suspended material at higher values than light based systems (Figure 3). Impedance is unaffected by the suspension. This leads to a practical device which consistently detects the yeast/beer interface as settled yeast is drawn from fermentation or conditioning tanks.

**Acoustic attenuation and impedance for measurement of suspended particles**

Acoustic attenuation is ideally suited to measure small numbers of particles in suspension. For example, Perlite is one of a number of filtration aids which in general have highly porous structures and high acoustic attenuation in suspension. This makes sound adsorption an ideal technique for measuring Perlite in sus-
TABLE 2
Change in impedance \((A_r/A_r')\) during fermentation.

<table>
<thead>
<tr>
<th>Apparent Gravity (°P)</th>
<th>Residual Gravity (°P)</th>
<th>Alcohol by Volume</th>
<th>Impedance Sugar</th>
<th>Impedance Alcohol</th>
<th>Combined Impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>10</td>
<td>0</td>
<td>0.9</td>
<td>1</td>
<td>0.900</td>
</tr>
<tr>
<td>7.5</td>
<td>8</td>
<td>1.26</td>
<td>0.92</td>
<td>0.992</td>
<td>0.914</td>
</tr>
<tr>
<td>5.1</td>
<td>6</td>
<td>2.52</td>
<td>0.94</td>
<td>0.984</td>
<td>0.925</td>
</tr>
<tr>
<td>2.6</td>
<td>4</td>
<td>3.78</td>
<td>0.96</td>
<td>0.975</td>
<td>0.932</td>
</tr>
<tr>
<td>0.2</td>
<td>2</td>
<td>5.04</td>
<td>0.98</td>
<td>0.967</td>
<td>0.948</td>
</tr>
</tbody>
</table>

Figure 4 shows the effect on attenuation and velocity of suspensions of PTFE particles of quite different mean particle sizes. Acoustic attenuation is substantially greater for the large particles, whereas velocity only changes in suspensions with small particle sizes. It is generally true for all materials that the concentration in suspension can be measured by changes in velocity when the particle size is small. The effect is frequency dependant, and in the case of the probe used, changes in velocity do not become apparent until the particle size is of the order of \(5\) mm. The ratio of velocity to attenuation would thus allow characterisation of the average particle size in suspensions in the range of \(0.1\) to about \(25\) mm.

**TABLE 3**
Acoustic properties of Perlite suspensions.

<table>
<thead>
<tr>
<th>Concentration (% dry wt)</th>
<th>Impedance ((A_r/A_r'))</th>
<th>Attenuation dB.m⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.945</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>0.990</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>0.720</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>0.660</td>
<td>-</td>
</tr>
</tbody>
</table>

**FIGURE 3**
Acoustic attenuation for measuring the concentration of yeast in suspension.

**CONCLUSIONS**

In conclusion, we have demonstrated a new instrument principal based on the sound properties of solutions and suspensions - acoustic impedance, acoustic attenuation and acoustic velocity - which has the potential to provide a practical solution for automation of several difficult analytical problems in the brewing process. This can be used equally well in the plant for process control and monitoring, or in the laboratory to automate current manual analyses.