

## Accurately Monitor Yeast Pitching Concentration in Beer Fermentation using In-Line Cell Density

**Introduction and Motivation** In beer brewing, concentrated yeast can be added to the fermenter at two critical steps: to begin the fermentation process, and to krauzen the beer. These two important steps affect the repeatability of the brewing process and can impact the flavor of the final brewed product. During fermentation, the yeast concentration grows exponentially to a high endpoint value. Real-time control of brewing processes therefore requires sensors having a wide dynamic range. To date, there has been a lack of sensors having good precision, accuracy, and linearity, combined with a wide operating range.

Traditionally, the yeast concentration was determined by off-line laboratory cell counting

measurements. Unfortunately, the relatively low accuracy of these laboratory methods, especially at low cell concentrations, and the inherent time delay in off-line measurements, makes advanced, real-time process control impractical. More recently, better control has been achieved by measuring yeast concentrations on-line using conductivity-based sensors or optical absorption devices based on incoherent light sources such as lamps or light-emitting-diodes (LEDs). Unfortunately, both types of sensors have limited performance and dynamic range. In this whitepaper, we will demonstrate the superiority of monitoring brewing processes using on-line, laser-based absorbance sensors.

### No Real-Time Process Control Available with Off-Line Laboratory Cell Counting

Off-line laboratory cell counting measurements typically suffer from dilution errors, sampling errors, and the delay associated with off-line sampling. These methods also do not offer the possibility of direct feedback to the process, because the yeast transfer is completed by the time that the measurement results are available. Moreover, the manual nature of sample handling can result

in widely varying laboratory results that depend on operator shift, specific personnel, or even laboratory workload delays. Since the pitching process duration is very short, and the result of the pitching process is so critical to the success of the ensuing fermentation, there is an obvious need for real-time control of this yeast addition.

### Conductivity-Based On-Line Yeast Concentration Monitors

Conductivity-based devices that measure cell density using cell membrane capacitance are being promoted for automatic control of yeast processes. Specifically, these sensors have been applied to yeast pitching, dosing and cropping, and for measuring low cell concentrations found in pitched wort and propagation vessels. These devices claim to measure cell viability (by differentiating between the capacitance of intact and ruptured cell membranes) and advertise that this viability information is important for improved process control: for example, to distinguish between yeast and non-yeast solids, or to separate high viability and low viability yeast. However, yeast viability is typically greater than 98% in both slurries and throughout the fermentation

process! Therefore, the claimed benefit of cell viability information is somewhat questionable, especially if it achieved at the price of lower precision and accuracy in the measurement of the actual yeast cell density. The real challenge to conductivity-based sensors is measuring yeast concentrations from zero up to 60% solids by weight in the fermentation vessels and transfer piping with high accuracy and precision.

More importantly, yeast pitching processes often undergoes significant flow and pressure fluctuations, because the feed mechanism used for moving yeast slurry into the transfer lines is challenged by the high density liquid. Conductivity-based devices are known

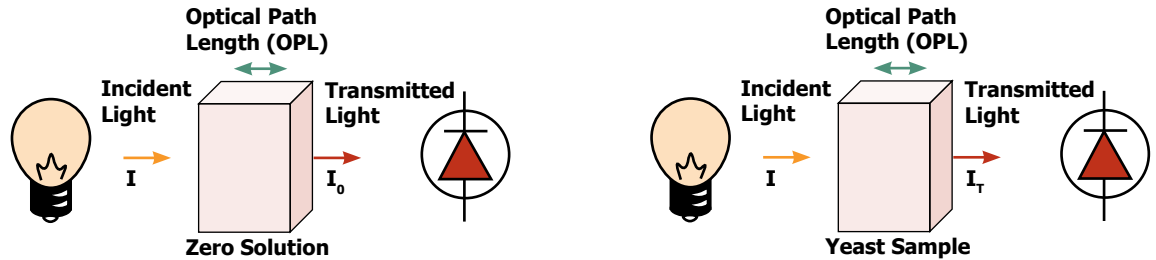


**Figure 1 Absorption Spectroscopy Principles Used in Optical Sensors**

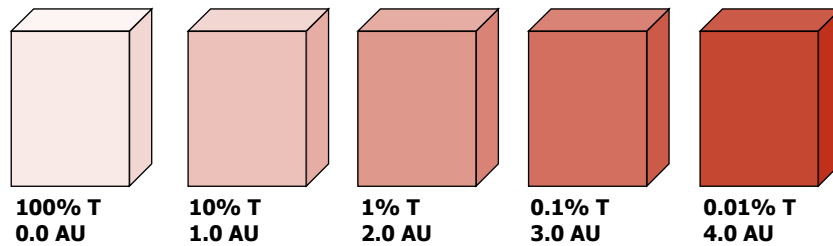
to be flow and pressure dependent in brewing applications, which limits their overall utility, as they respond more strongly to flow or pressure changes than the actual yeast concentration.

The high pressure variations encountered in the transfer lines can also damage the small electrical pins that form the conductivity sensor. Any physi-

cal changes in the spatial orientation of these pins can either completely destroy the sensor or invalidate its calibration. The general robustness and reliability record of conductivity sensors remains poor for brewing applications. These ongoing (replacement) operating costs further worsen the economics of using conductivity sensors, which have a high entry point (\$20,000).



**Absorbance [AU] = A =  $-\log_{10}(I_t/I_0)$**   
**Absorption = a = A/OPL**  
  
 **$I_t$  = Light transmitted through sample**  
 **$I_0$  = Light transmitted through zero/reference solution**

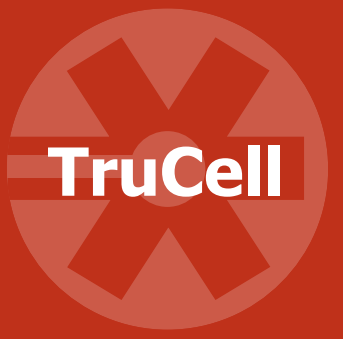


### Early Attempts at Optical On-Line Yeast Concentration Monitors

Optical devices based on absorption have been proposed as an alternate to expensive and unreliable conductivity sensors. These optical sensors use broadband incoherent light sources, such as filtered incandescent tungsten bulbs or NIR-LEDs in the 850-900nm range. The source light travels through the liquid sample, by means of a physical gap, and is captured by a photo-detector. The sensor measures the amount of transmitted light through the sample, and computes the sample's optical absorption (figure 1). Owing to their simplicity, optical sensors are typically much less expensive, more robust, and generally better suited for concentration measurements.

In brewing applications, however, the use of optical devices has been limited to date, by their

inability to accurately measure high concentrations of yeast. Typical yeast pitch concentrations range from 35% to 45% solids, and such media are very highly absorbing. This means that the sample is very opaque (or dark), and few of the photons from the light source actually reach the detector. Because traditional optical devices rely on incoherent radiation light sources, the achievable power density (number of photons per area) of a collimated light beam at the wavelength of interest is low, and becomes even smaller after transmission through the yeast sample. The photo-detector signal is therefore very weak. In order words, the signal to noise ratio at the photo-detector is poor, and the optical device cannot provide a precise or accurate signal. Even if the optical path length through the sample is reduced, in order to minimize the amount of absorption,



the performance remains limited, as the inherent problem is the type of light source used: there is simply not enough incident light to effectively pen-

etrate the concentrated yeast sample and provide a robust optical signal at the photo-detector.

### TruCell laser-based Yeast Concentration Monitors

The Finesse TruCell monitor uses a different type of light source, namely, a laser. Lasers provide coherent radiation, which means that they have narrow emission bandwidths (< 10 nm), and are easily collimated to cylindrical beams. Because the laser emission is narrowband (unlike LEDs or lamps where at least 50% of the output power is lost by filtering to a narrower emission bandwidth) and can be efficiently collimated (unlike in LEDs or lamps where at least 50% of the output

power is lost), most of the laser light available for transmission through the sample (compared to less than 10 to 20% for LEDs and lamps). For a given light source power, more photons are transmitted through optically dense (highly absorbing) sample media by the laser. Therefore, more photons reach the photo-detector and produce a higher signal-to-noise ratio. In turn, a higher signal-to-noise ratio improves measurement precision and accuracy.

**Figure 2**  
Comparison of Absorbance Response Between Optical Sensors Using Incoherent and Laser Light Sources

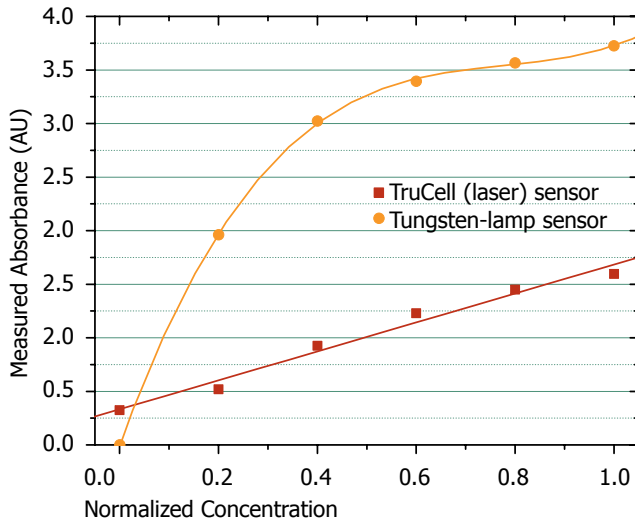
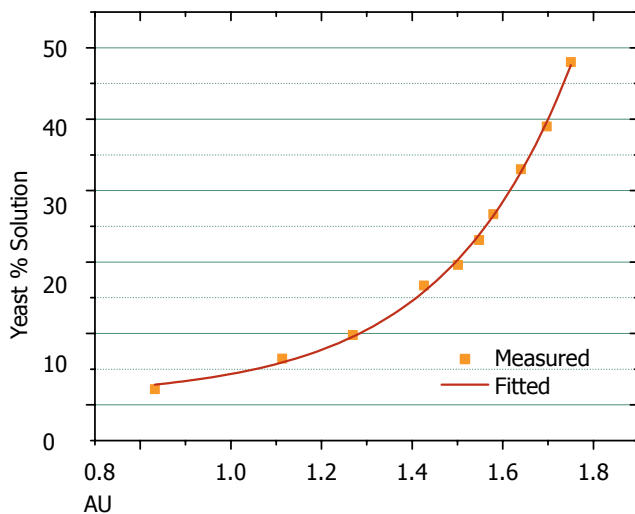


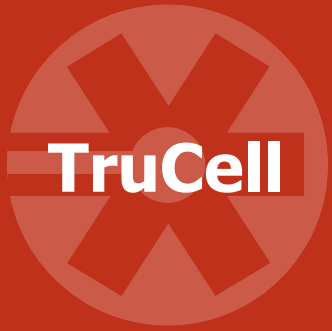
Figure 2 shows the concentration response of the Finesse TruCell laser-based sensor compared to a competing tungsten lamp based optical sensor. The tungsten lamp based sensor response has a higher slope and saturates above a certain concentration. Such non-linear behavior indicates that at high concentrations, the sensor “runs out of photons”, namely that it cannot respond effectively to concentration changes and its precision degrades. Such non-linear behavior makes calibration of the AU values to a control parameter more difficult, and the resulting calibration less robust (errors are more easily introduced at high concentrations). These measurements also provide less overall accuracy.

**Figure 3**  
Response of TruCell AU versus Yeast Concentration



In contrast, the TruCell response demonstrates excellent linearity over the entire concentration range, making the calibration of the AU reading to the process control parameter straightforward. Moreover, the TruCell sensor is nowhere near the onset of its response non-linearity, which indicates that it has “photons to spare”, and will provide excellent signal-to-noise and precision in its measurements.

Figure 3 shows the response of a TruCell sensor to high concentrations of yeast slurry used in pitching. The growth curve is exponential, and the AU correlation to yeast % solids is excellent, even at high yeast concentrations (close to 50%). TruCell sensors have been successfully used to monitor and control yeast pitching, as well as to maintain proper yeast concentrations during both initial pitch and krauzen yeast additions.



## **Benefits of TruCell for Accurate Monitoring and Control of Yeast Pitching**

Using advanced in-line optical cell density monitoring, brewers can develop and implement more precise control strategies for controlling the yeast

pitching process. These controls will provide better batch-to-batch repeatability and help prevent undesirable flavors in the final beer.