Improving Biorenewables Production with the IRmadillo In-line Process Analyser

IRmadillo™

What is it?

The IRmadillo is an in-line process analyser based on infrared light. It works by using a technique called FTIR spectroscopy to monitor the concentration of different chemicals in liquids in real time.

What makes it different to other analysers is that it's built to last. Not only last, but it's built to survive and built to perform in industrial environments.

There are no moving parts, and the light source inside it runs at a low power. The lack of moving parts makes it very stable, so you can fit it and forget about it.

Why should I use it?

The IRmadillo monitors what's going on in your process as your feedstock is converted into product, in real time.

There are three main ways you can benefit from better bioprocess monitoring with the in-line IRmadillo analyser, all of them leading to improved return on investment:

- **Improve your yield**

By having a trustworthy real-time measurement of the process you can run closer to maximum operating limits (e.g., allow acidity to run high without de-activating an enzyme).

- **Improve your capacity**

Identify the exact moment when a batch process has consumed its feedstock and reached optimum product level, then stop the process. Relatively small increases in turnaround time add up over a year's production schedule – how much is each extra batch per year worth?

- **Resolve problems early**

The IRmadillo lets you see exactly what's going on in your process, so if something does go wrong you have time to fix it and not lose the batch (e.g., removable or resolvable contamination, the need to add extra reagent/enzyme or similar).

Empowering Decisions

The IRmadillo empowers you to understand what your process is doing, and then make informed decisions about how to improve or control it — something that is simply not possible with off-line sampling.

How do I use it?

The IRmadillo is a versatile process analyser based on FTIR spectroscopy. This means you can use it for concentration monitoring (quantitative analysis) or for condition monitoring (qualitative analysis).

Quantitative analysis

The IRmadillo will output the concentration for each of the different chemicals that it has been calibrated to detect in your process. Example chemicals are:

- Sugars
- Organic acids
- Alcohols (both mono-alcohols such as butanol and ethanol, but also di-ols and tri-ols such as glycerol)
- Soluble lignin
- Furan and furan derivatives
- Sulphates, thiosulphates and sulfides

There's no maximum concentration, and the scales can be adjusted depending on the chemical of interest. So you can monitor sugars in % terms while keeping an eye on ppm level organic acids at the same time.

Qualitative analysis

The IRmadillo will give you readings such as "within specification", "contamination spotted", or "process out of specification", for example. The calibration in this case is much more flexible, and is designed to show overall types of process conditions rather than fixed chemical concentrations.

We can also build a qualitative calibration after you've been using it for a while to look back at "good batches" and "bad batches", and give you an indication of where your batch is likely to go over time.

You can run both a **quantitative** and **qualitative** calibration **at the same time** – no need to choose.

What will I see when I use it?

The IRmadillo software contains its calibration and runs the measurement in real time. This means you'll get frequent updates on chemical concentrations (normally in %wt but that can be changed to whatever units you're used to using) over the whole process.

The graph below shows an example series of lignocellulosic hydrolysis batches. These batch trends can then be exported into text files for further analysis by your team for process optimisation if needed.

The IRmadillo will also talk to your existing plant communications setup. The standard communications protocols are OPC-UA or Modbus (TCP/IP and RTU/RS485 are both supported). Additional protocols are available if needed.

A 38 mm diameter probe is very large - how can I use it with my 1 L fermenter?

The IRmadillo is designed for industrial, in-line & on-line manufacturing control and monitoring, so can be difficult to use in a laboratory. If you need to run small-scale (such as 1 L) fermenters to build calibration models we can provide accessories such as flow cells or sample cells to help build the calibration.

If your process is entirely at the 1 L scale you're probably too early in the development pipeline to truly benefit from in-line spectroscopic-based PAT as your process is likely to change too much to build helpful calibrations. But once you're at manufacturing scale we're ready to help!

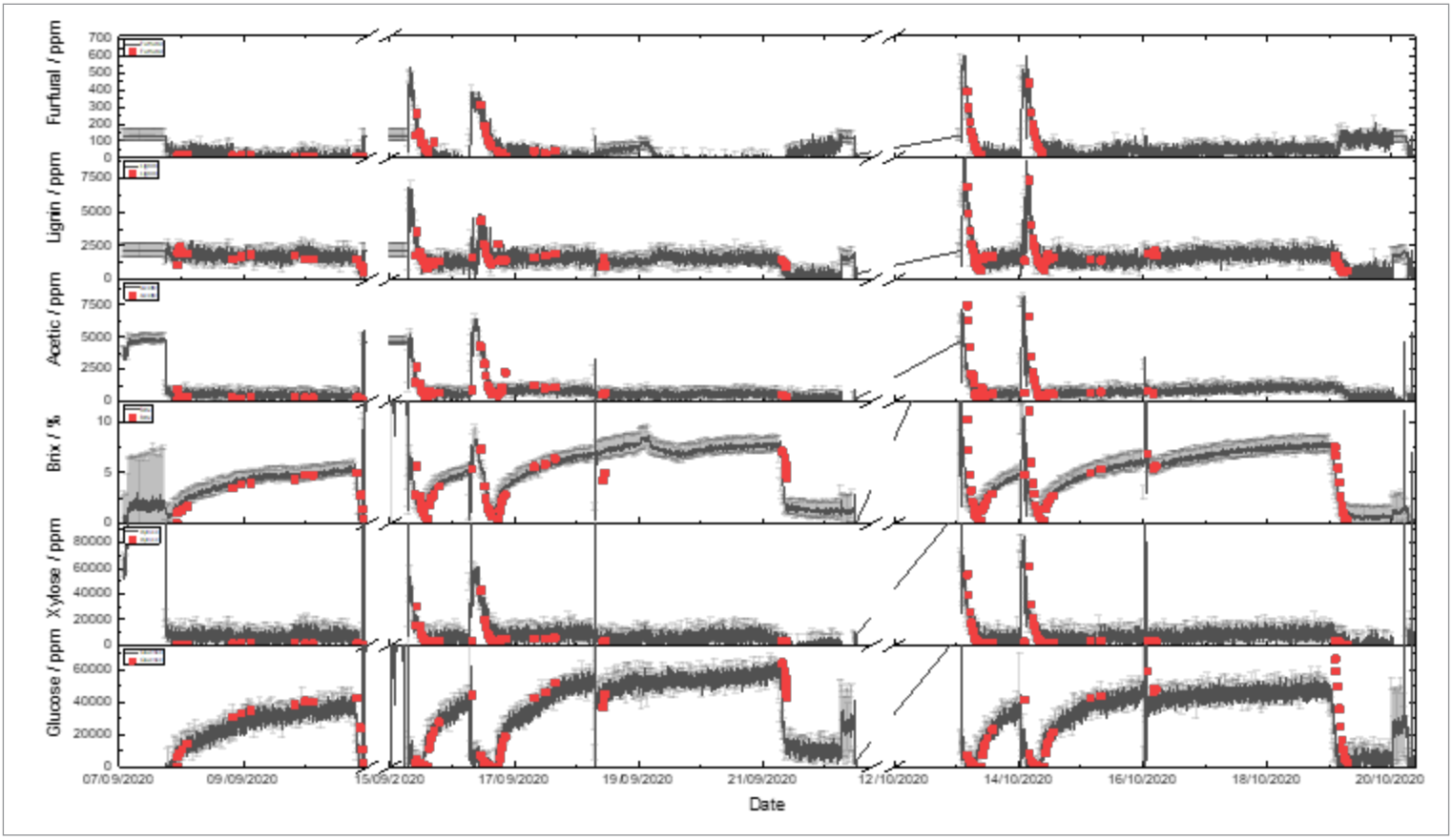

Figure 1: Lignocellulosic hydrolysis processes over time – the IRmadillo has excellent correlation with the off-line reference data for a range of chemicals in real time. Black lines show IRmadillo measurements and the red dots show laboratory sampling.

I tried FTIR before and it didn't work... and what about Raman?

Don't confuse **FTIR** (mid-infrared) with FT-**NIR** (near infrared). Infrared light comes in a few different wavelengths, and there was a big push a few years ago to get near infrared instruments (FT-NIR) into manufacturing plants.

Near infrared (NIR or FT-NIR) is very different to the FTIR mid-infrared light that the IRmadillo uses. FT-**NIR** instruments don't actually look directly at the chemical bonds, but at "overtones". This is a bit like trying to recognise someone from their shadow rather than looking at their face. It gives you a rough idea who it is, but to get full understanding you need the full picture. They also use a probe with a reflecting window in it that can easily get blocked with high solid loadings – such as when there's high biomass in the process.

Raman spectroscopy looks at similar features to mid-infrared, but the mechanism behind it is completely different. In Raman a laser is used to cause the spectroscopy, and this can be badly affected by fluorescence (which many bioprocesses exhibit) or by the presence of biomass or bubbles. This means in general Raman is not the technique of choice for biorenewables.

We give an example of this in Figure 2, showing a comparison of an FT-**NIR** instrument, a Raman and a mid-infrared IRmadillo all monitoring the same sucrose fermentation. The IRmadillo has no trouble monitoring the process and performs well. The NIR simply cannot differentiate between glucose and fructose, making it unreliable and unable to provide any meaningful information. It also shows worse results when the biomass is high – such as before the sugar feed at 23 hr and towards the very end of the process.

The Raman instrument performs better – because it looks at the fundamental information in the same way the IRmadillo does. But it starts to struggle when the biomass is high. This is probably a combination of fluorescence issues and "light scattering" – something that can cause substantial problems with laser based systems such as Raman.

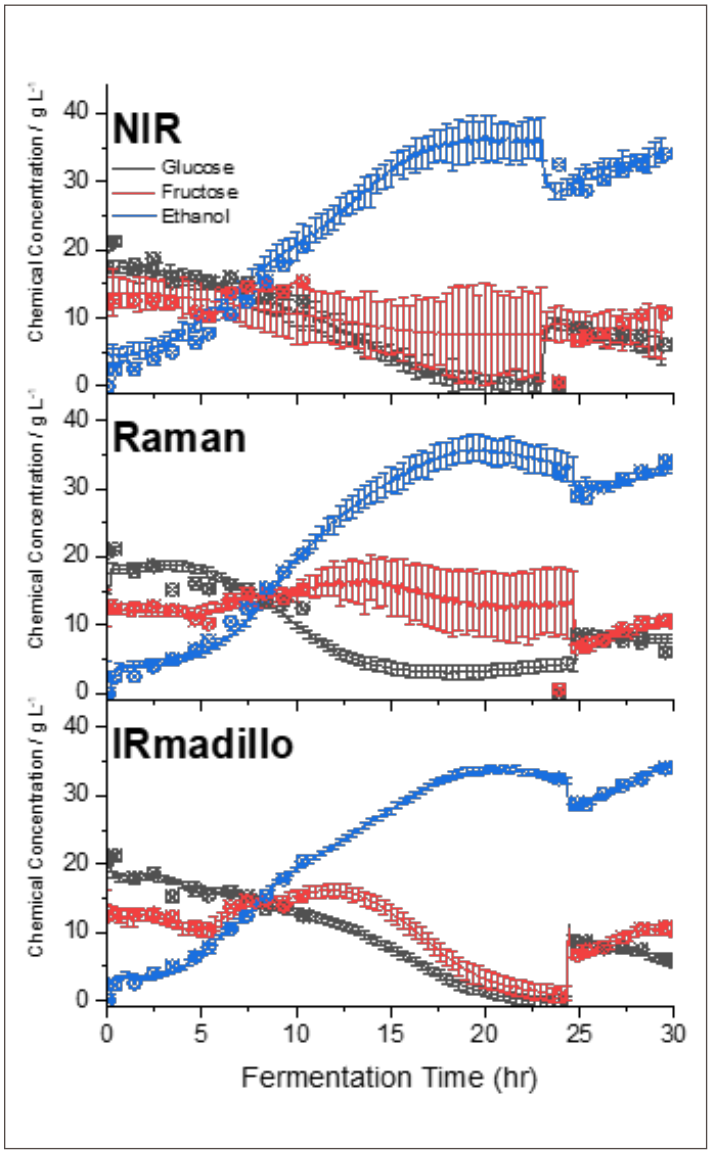

Figure 2: Comparison of three spectroscopic instruments: near infrared (FT-NIR), Raman, and the IRmadillo (FTIR), monitoring a fermentation process over 30 hrs. Note the much larger error bars on the FT-NIR analysis (top), making differentiation nearly impossible between glucose (black lines) and fructose (red lines); meanwhile the IRmadillo (bottom) clearly defines each component. The Raman instrument (middle) performs better than the NIR but struggles towards the end of the process and immediately before a sugar feed (at 23 hr). This is due to high biomass at this point – something Raman instruments can have an inherent difficulty with.

I have multiple vessels – Do I have to calibrate every instrument?

No! We perform a single calibration built across all the IRmadillos you purchase. One set of models to maintain – dramatically reducing maintenance costs.

What's the performance of the instrument?

The exact performance depends on the process you use, but a typical error of measurement is shown below.

Chemical	Measurement error / %wt
Xylose	0.5
Glucose	0.5
Furan	0.003
Lignin	0.05
Acetic acid	0.03
Ethanol	0.7
Formic acid	0.01

The IRmadillo does not try to out-perform HPLC for error and detection limits, but it can give so much more information over a much shorter time. It also tells you when to take an extract for HPLC — using your staff much more efficiently and effectively.

Interested in finding out more?

Visit our website to read more about our instrument, application notes and technical details.

Contact us and let us know more about your process monitoring and what you'd like to measure in real time.

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I'm interested. What's next?

Keit gives you options to make it easy to start using an IRmadillo. For all options, we'll help you install, train your team, and we can even calibrate a chemometric model.

Rental

Want to try one out? Keit will provide an IRmadillo suited to your process operating environment and bill you monthly for an agreed span of time. Easy to renew, you have control over how long you keep it — from a few months to an even longer rent-to-own plan.

Purchase

Own your IRmadillo outright to monitor your process on-line and in real time as you see fit.

Begin your discussion today on how you can get an IRmadillo installed into your system.
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IRmadillo™

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