BevSense

Mid Infrared On-Line Ingredient Sensors

Testing ingredients at Critical Process Points (CPCP) in the Brewing and Packaging Process

Applications: Dissolved CO_2, Ethanol and Real Extract *(Er)*

New Problems in Beer Production

- High Gravity Brewing has made blending more challenging
  - higher starting ethanol
  - more adjusted water
  - Fast measurement speed necessary
  - Uniform blending is necessary for accurate inline measurement

- CO_2 injection is now much higher
  - high gravity beer is higher in ethanol content yet has the same amount of CO_2 as non-high gravity beer. High CO_2 injection often causes cloudy beer in the blending lines due to un-dissolved CO_2.

- Process temperature increases due to sustainability practices increase pressure
  - Dissolved CO_2 levels in beer a bigger problem. Much higher pressures are required, increased time and surface area is required to dissolve CO_2.

New Problems in Beer Production (continued)

- Ethanol and Extract are traditionally measured using Density and sound velocity, physical parameters that are affected by recipe change
  - New ingredients: honey, lime, fruits, HFCS, other fermentable sugars change the relationship between density, sound velocity, ethanol and sugar. This causes the density and sound velocity instruments to be less desirable and less effective as measuring techniques.

- CO2 is traditionally measured by temperature and pressure
  - High speed bottling lines have increased line pressure spikes. Sudden pressure changes affect CO2 instruments using parameters such as pressure and temperature, causing apparent out of spec. process conditions, increasing line stops.

New Problems in Beer Production (continued)

- Ethanol ABV inline measurement has become less accurate
  - Increased process temperature variance
  - *ethanol volume is highly dependent on temperature, similar to mercury* in a thermometer– as the temperature gets higher, ethanol volume increases.
- Ethanol weight by weight is temperature independent. Measurement must be taken by weight and the volume then calculated mathematically.

- Since ethanol level is the basis of tax, accurate measurement of ethanol is vitally important!

Mid-IR Sensors *MIRS sensors address new issues*

- MidIR sensors ("MIRS") simplify the process.
  - MIRS are ingredient sensors, additives and different density ingredients are invisible to the concentration.
  - Ethanol sensor measures ethanol
  - Sugar sensor measures sugar (at any point in the process)
  - CO_2 sensor measures only CO_2, not all dissolved gases.

- MIRS are measuring ingredients
  - process induced pressure spikes do not affect measurement.
  - MIRS only measure Sugar, Ethanol and CO2 not affected by new ingredients

- MIRS only measures dissolved ingredients.
  - Can cause short term process problems
    - Beer must be fully blended and CO_2 must be dissolved in the blending process)
  - Correcting these problems during blending prevents problems downstream, such as inhomogeneous tanks.
  - A sight glass across from the sensor allows us to determine post sensor restrictions,
  - Increased surface area for CO_2 injection and/or static mixing is needed to dissolve the gas and fully blend the beer before measurement. In beer headspace it takes 24 hours for .5 (v/v) of CO_2 to dissolve into the fluid for a large tank.

Mid-IR Sensors

Critical Process Control Points in Brewing and Packaging Processes

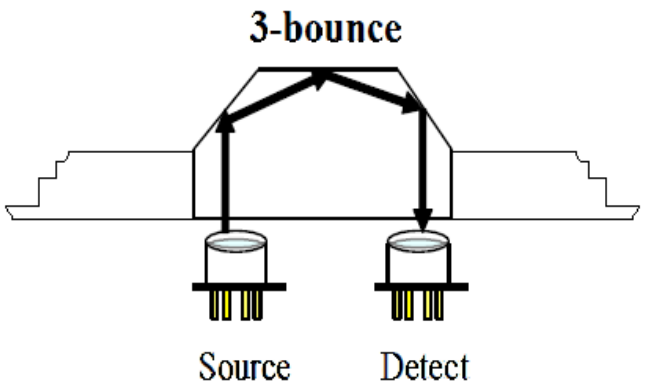
Parameter	Critical Process Point	Measurement	Ingredient/Parameter	Direct/Indirect	Definition
Original Gravity	Wort	Density	Parameter	Indirect measurement of Original Extract. Measures total fluid density not fermentable sugars	The density of the wort before fermentation
Original Extract		Mid Infrared	Ingredient	Direct measurement. Measures sugar	The amount of fermentable sugars in wort units Plato/Brix
		Density		Indirect measurement calculated from Original Gravity	
Extract	Blending	Density/Sound Velocity	Ingredient	Indirect uses density to measure fluid sound velocity to separate out sugar fromEthanol	The amount of residual sugar in the high gravity beer
		Mid Infrared		Direct measurement of sugar molecule	
Ethanol (w/w)		Density/Sound Velocity	Ingredient	Indirect uses density to measure fluid sound velocity to separate out sugar fromEthanol	The amount of ethanol in the beer. This is the preferred Parameter for accurate blending
		Mid Infrared		Direct measurement of ethanol molecule	
Ethanol (v/v)		Density/Sound Velocity	Parameter	Indirect calculated from gravity sound velocity and temperature	The volume of ethanol in beer at 20C. Dependent Caluclated using Temperature Ethanol (w/w) and specific gravity does not exist in pipe
		Mid Infrared		Indirect calculated from Ethanol (w/w) Real Extract and temperature	
CO2 (v/v)		Mid Infrared	Ingredient	Measures molecule	The amount of carbonation in beer measured (volume/volume)
		Temperature/Pressure	Parameter	Meaures CO2 assuming beer is 3.8% (w/w)ethanol 1.010 Specific gravity using Henry's Law	
Original Gravity	Blending/Bottling	Density/Sound Velocity	Math term	Does not exist in fermented beer	Used to calculate Extract/Ethanol for Density sound velocity
Original Extract		Density/Sound Velocity	Math term	Does not exist in fermented beer	
Apparent Extract		Density/Sound Velocity	Math term	Does not exist intermediate math term for density sound velocity calculation	The apparent amount of sugar in fermented beer by a density measurement before Ethanol and Extract are mathametically seperated
Ethanol (w/w)	Bottling	Density/Sound Velocity	Parameter	Formula based on density/apparent extract/Unfermentable sugars (sound velocity)/Original Gravity	*See definitons above*
		Mid Infrared	Ingredient	Sensor measures ethanol	
Final Extract (Plato)		Density/Sound Velocity	Parameter	Formula based on density/apparent extract/Unfermentable sugars (sound velocity)/Original Gravity	
		Mid Infrared	Ingredient	Sensor measures sugar	
CO2 (v/v)		Temperature/Pressure	Parameter	See definition above	
		Mid Infrared	Ingredient	Measures molecule	

Mid-IR Sensors *BevSense VS3000E Measuring Method*

***MIRS* is a Mid-Infrared Spectrometer using Attenuated Total Reflective Index and Beer-Lambert's Law**

- Infrared Source emits IR energy through the sapphire crystal into solution

- IR energy bounces three times off the crystal and returns to the IR detector; the signal loss or absorption is additive to the number of ATR bounces



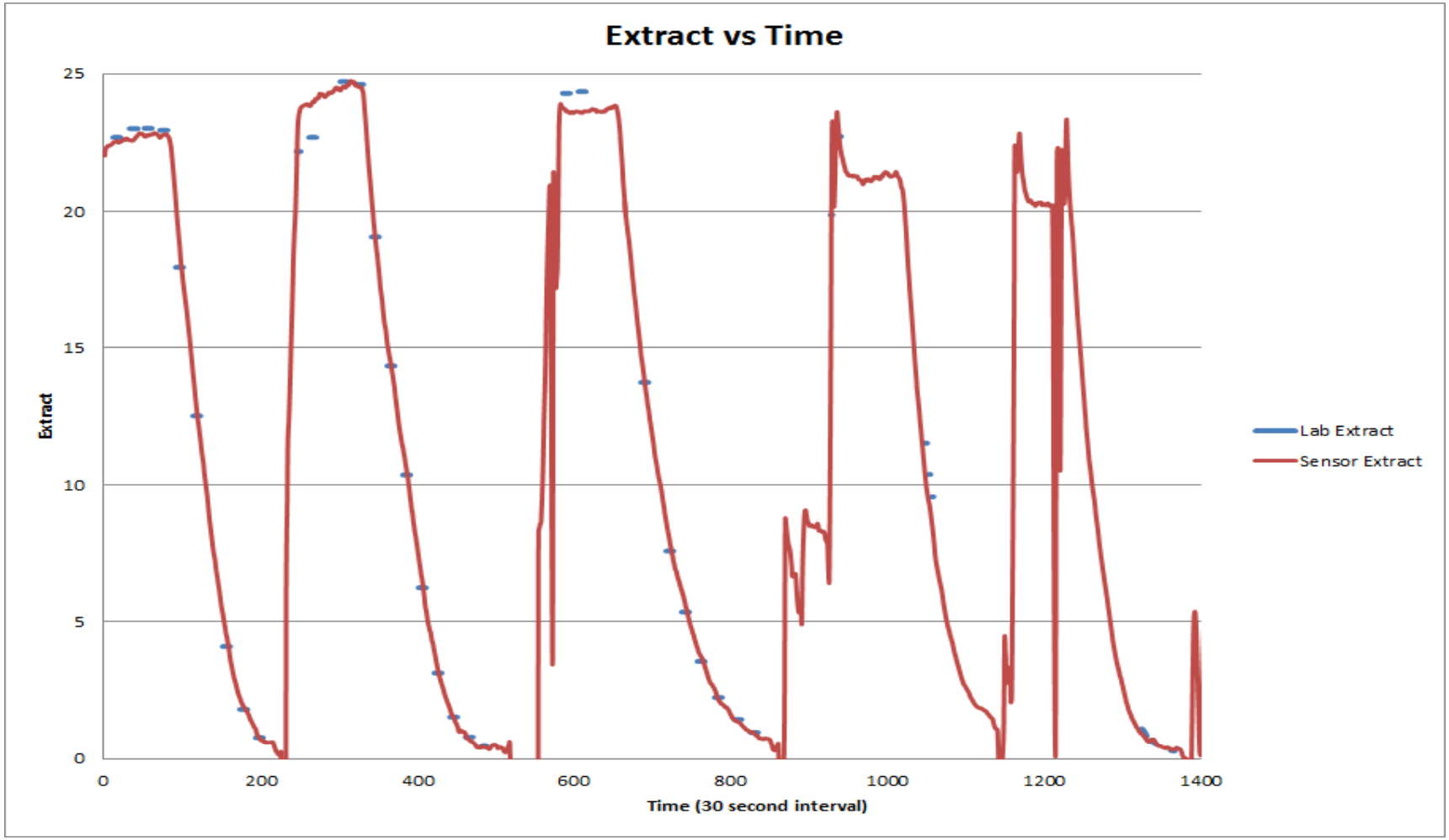
- IR detector determines how much energy was absorbed in the beer based on molecular vibration of the CH stretch for Ethanol and Plato (via Beer-Lambert's Law), and the molecular vibration of CO_2 for CO_2.

- Each concentration of interest is measured independently and has its own optical filter designed to make the sensor active for only the molecule of interest.

Mid-IR Sensors

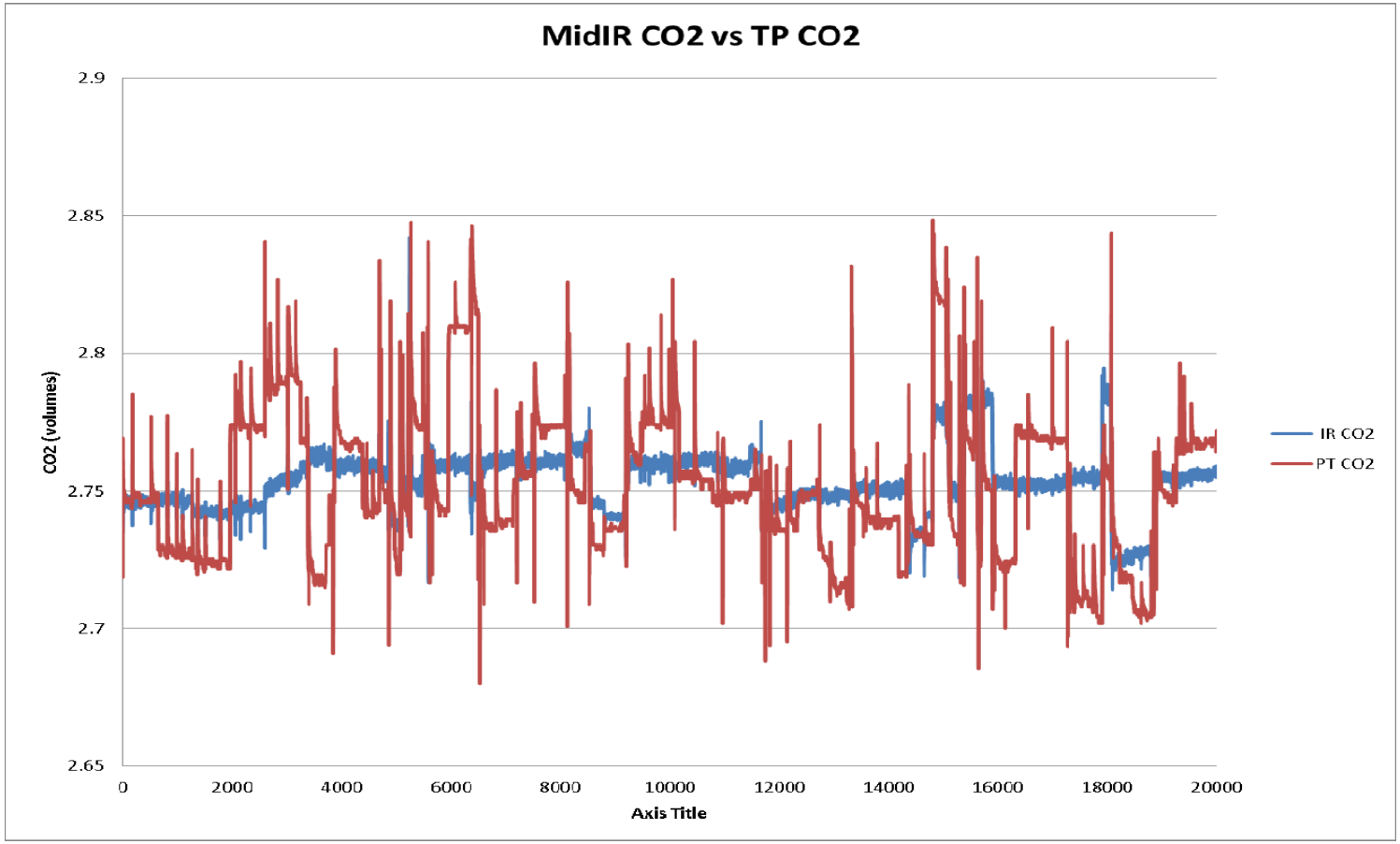
Critical Process Control Points in Brewing and Packaging Processes

- MIRS can be used to measure wort online. Blue dots are actual lab measurements



Mid-IR Sensors

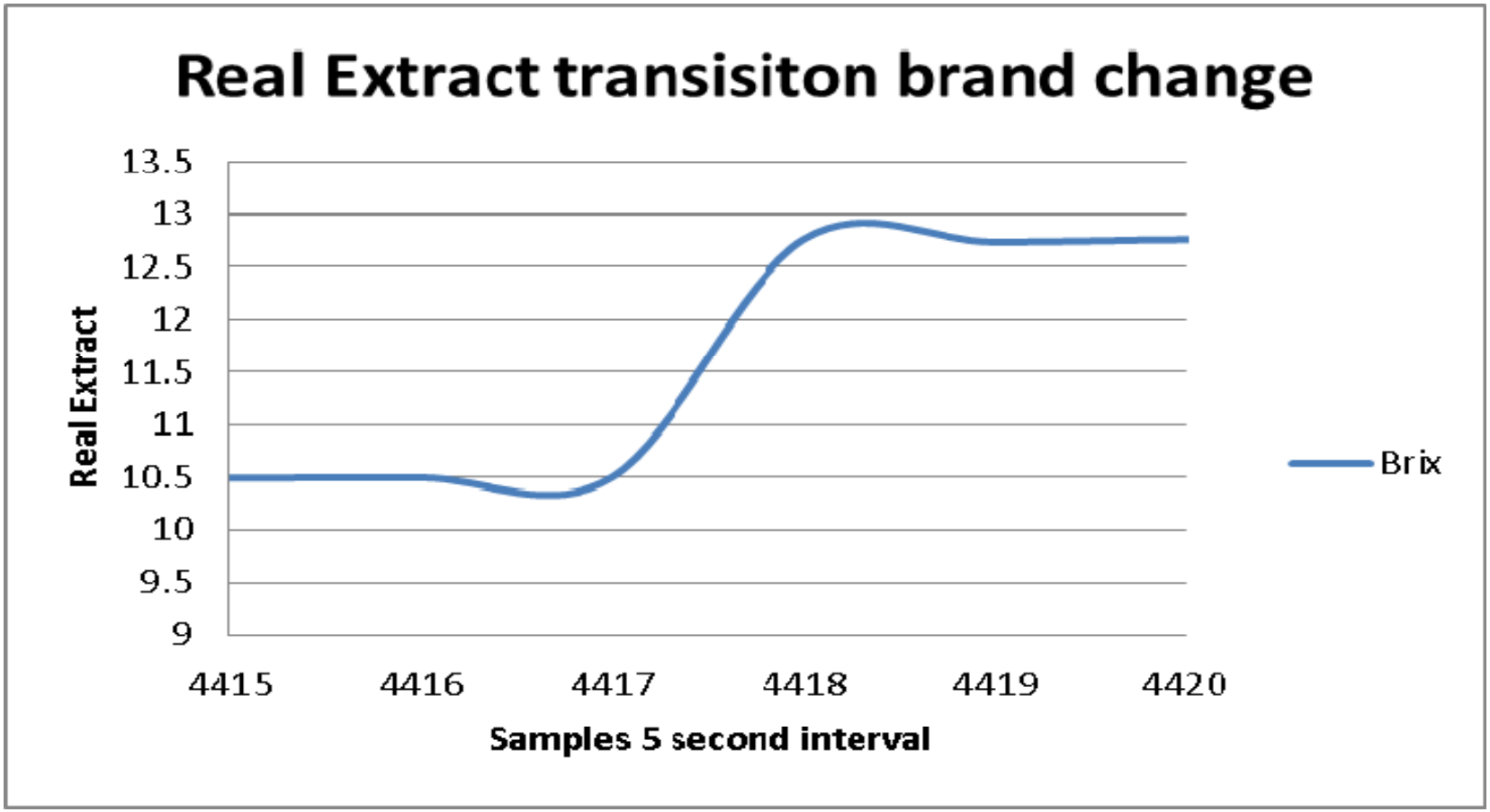
CO_2: MIRS vs. Temp-Pressure on finishing line



MIRS immune to line pressure fluctuations, eliminating false alarms due to line pressure variations. MIRS has lower variance because of immunity to specific gravity changes not corrected for in PT Henry's Law calculation.

Mid-IR Sensors

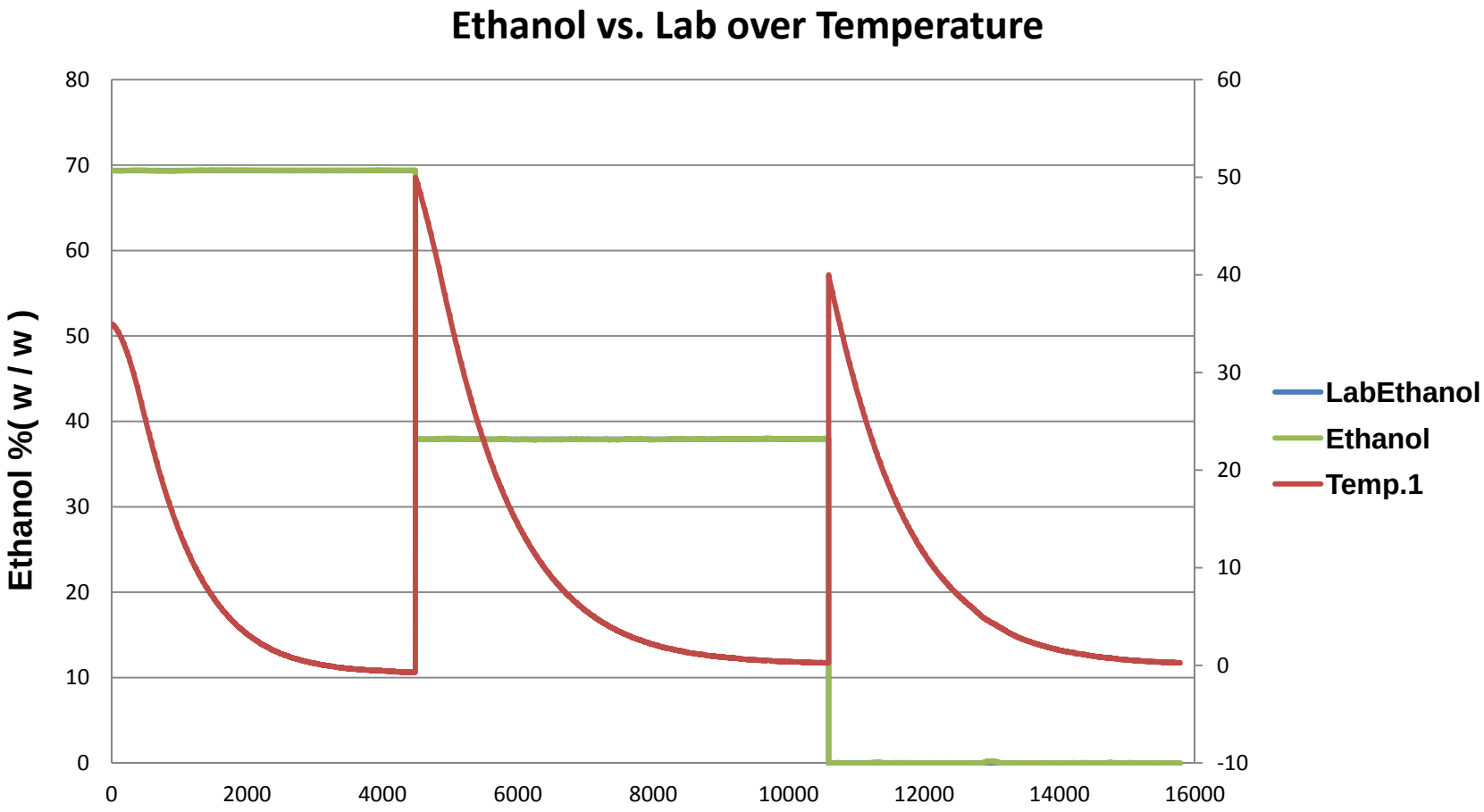
BLENDING - MIRS high speed gives fast brand transition.



- 24 measurements per second
- Transition speed now blender-driven versus sensor response
- The process is now slower than the sensor, rather than the sensor being slower than the process

Mid-IR Sensors

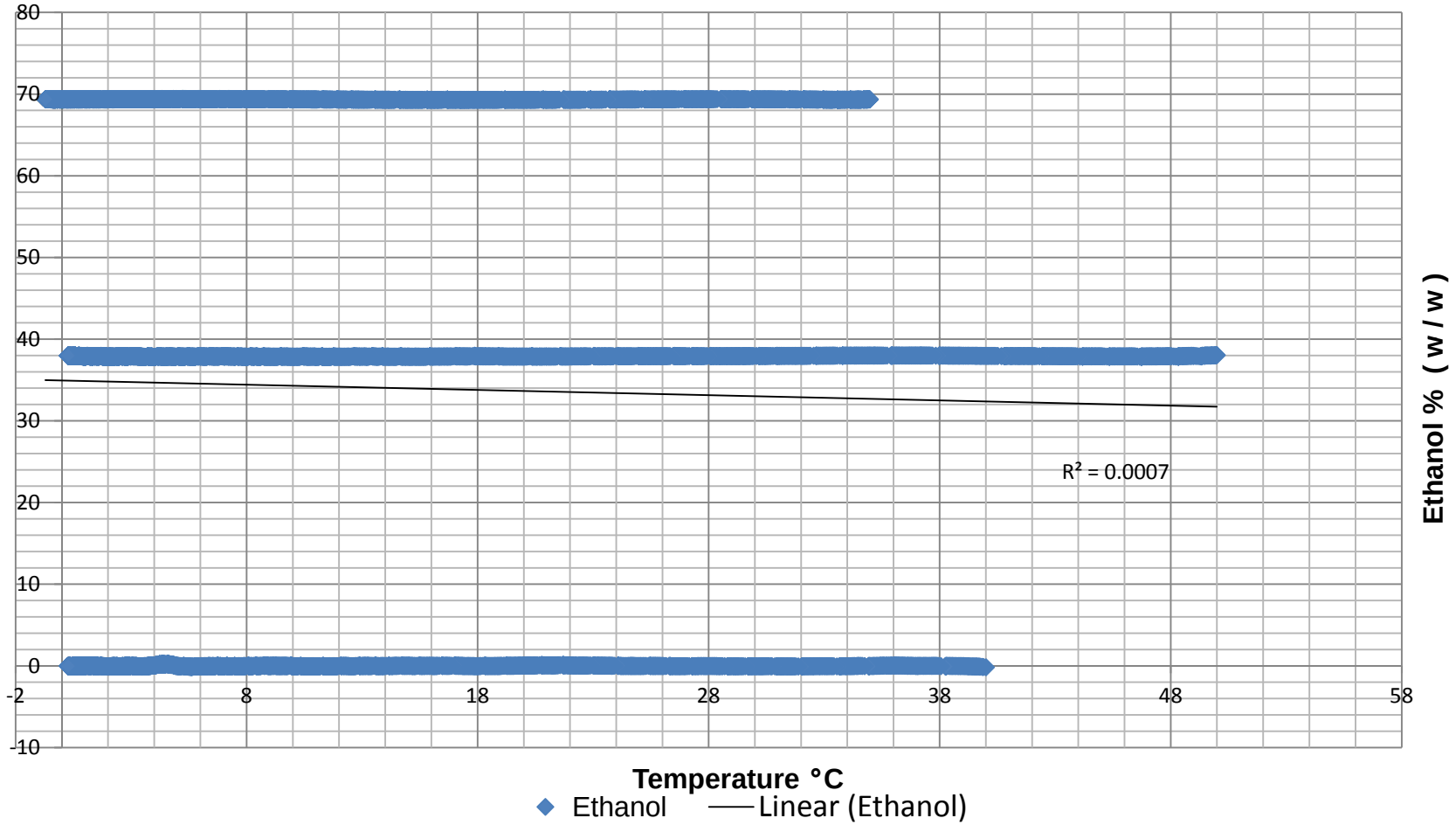
Temperature Immunity of MIRS



- Ethanol vs. Lab Ethanol vs. Temperature
- Ethanol is actual VS-3000 data taken in w/w units. Data taken in a Tenney temperature chamber showing temperature immunity of MIRS measurement.

Mid-IR Sensors

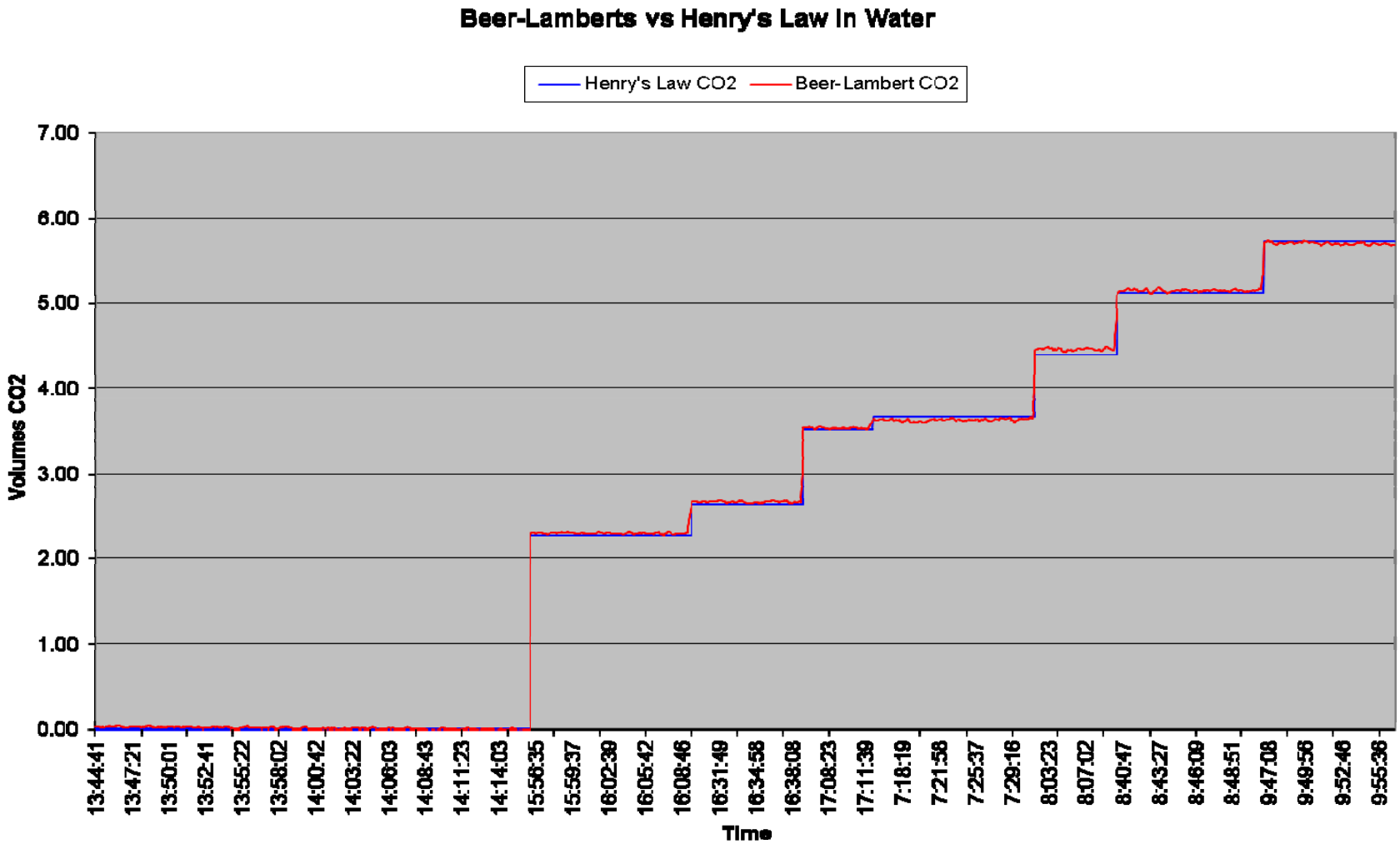
MIRS Temperature vs. concentration regression Improved Sustainability



- Ethanol shows immunity to process temperature
- Concentration temperature independence from 0° to 50°C
- Straight line of temperature vs. concentration shows temperature independence
- Regression was .0007% but trend line shows superior independence

Mid-IR Sensors

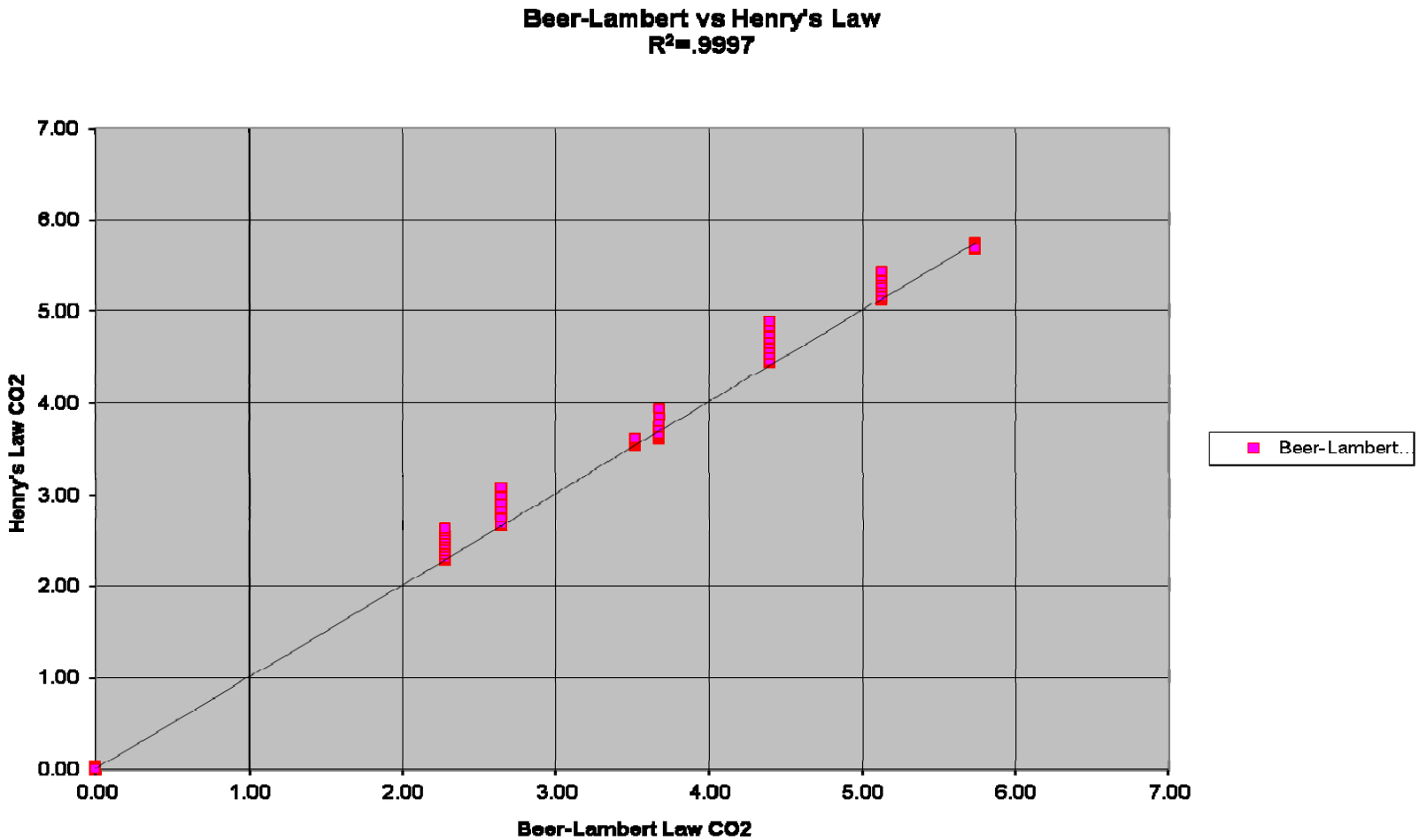
Pressure-Temperature (P-T) vs. MIRS CO_2 Data - Dissolved in Water



- In water, perfect correlation between Henry's Law and Beer-Lambert's Law
- Changing ingredients make Henry's Law correlation inaccurate - using temperature and pressure is accurate only in water

Mid-IR Sensors

Regression showing correlation of Pressure-Temperature (P-T) and MIRS in water



- PT and MIRS are equivalent in water
- In 2010, the ASBC acknowledged that CO_2 solubility in ethanol is 10x that in water, therefore, PT measurements are proportional to ethanol, not CO_2 by including VitalSensors' carbonation calculator in the ASBC standards

Mid-IR Sensors ***Benefits of MIRS Technology***

•. System footprint is small
- requires significantly less infrastructure then mechanical technology. No routine maintenance, No moving parts, No consumables……

• One process connection requires only 10mm wrench to install
- One sensor head measures up to three ingredients: Extract, Ethanol and CO_2..

• MIRS are truly in-situ
- Beer immerses sapphire crystal in direct flow. CIP immune, cleaned at up to 185°F for standard models and 248°F for extended temperature configurations System footprint is small
- No pneumatic cylinders or pumps required for drawing CO_2 into offline chamber
- No side-stream "U-tubes" for inferring ethanol via density, permitting full product flow. More sanitary.
- MIRS contains no moving parts or consumables (such as membranes). No annual maintenance expenses.

Mid-IR Sensors ***MIRS does not affect process***

- MIRS concentration readings are not affected by or dependent on temperature, pressure, density, color, turbidity or flow.

- CO_2 measured 24 times per second based on spectral measurement of the CO_2 molecules. *MIRS* does not rely on pressure-temperature.

- Ethanol measured 24 times per second based on spectral measurement of the ethanol molecules. *MIRS* does not use density or sound velocity

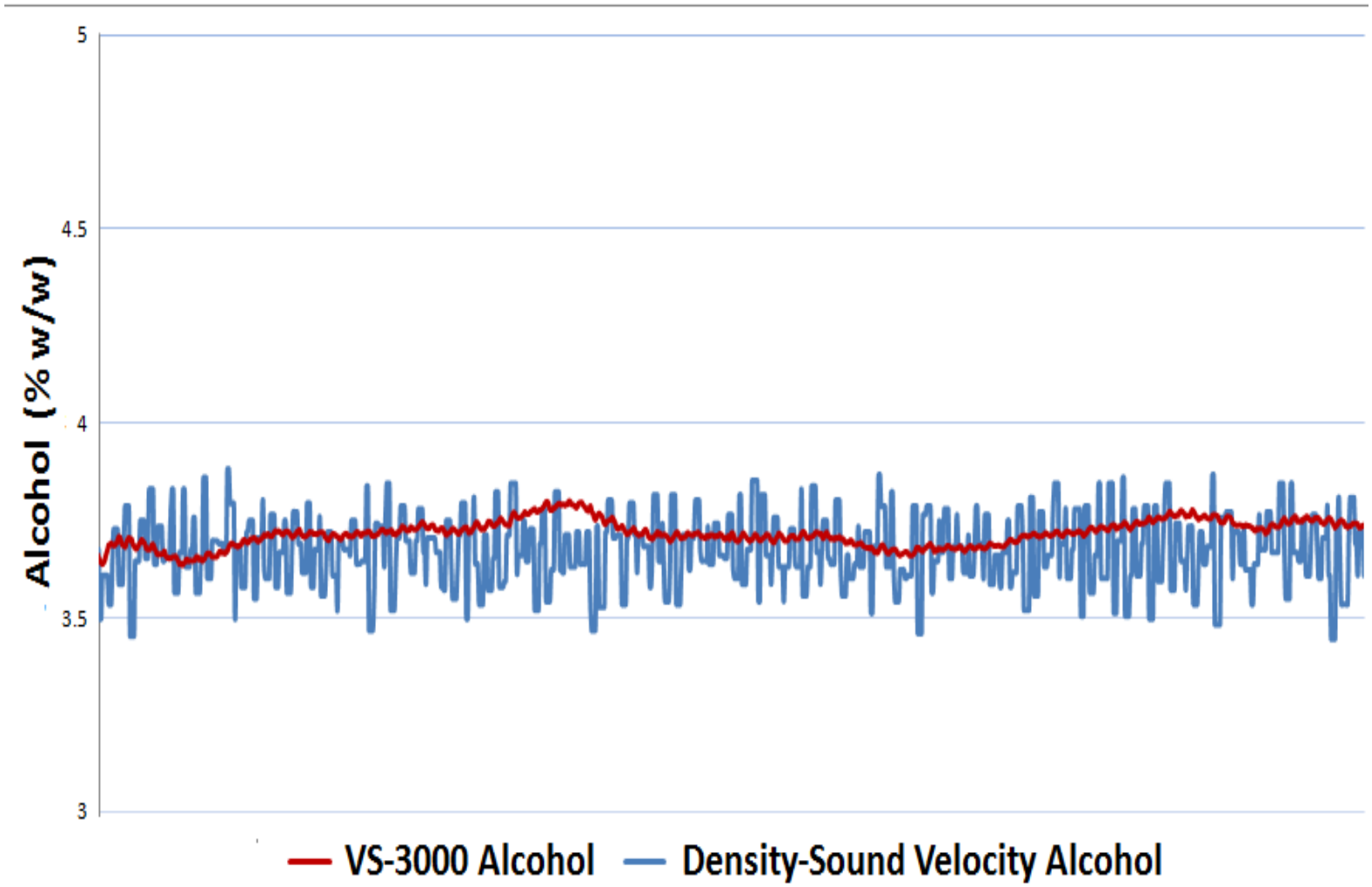
.

- Real Extract (Er) measured 24 times per second based on spectral measurement of sugar. *MIRS* does not calculate using density or sound velocity (to measure un-dissolved sugars).

- Eliminate false production alarms caused by valves, pressure spikes, line stops & mechanical instrumentation errors. *MIRS* reads the molecules directly.

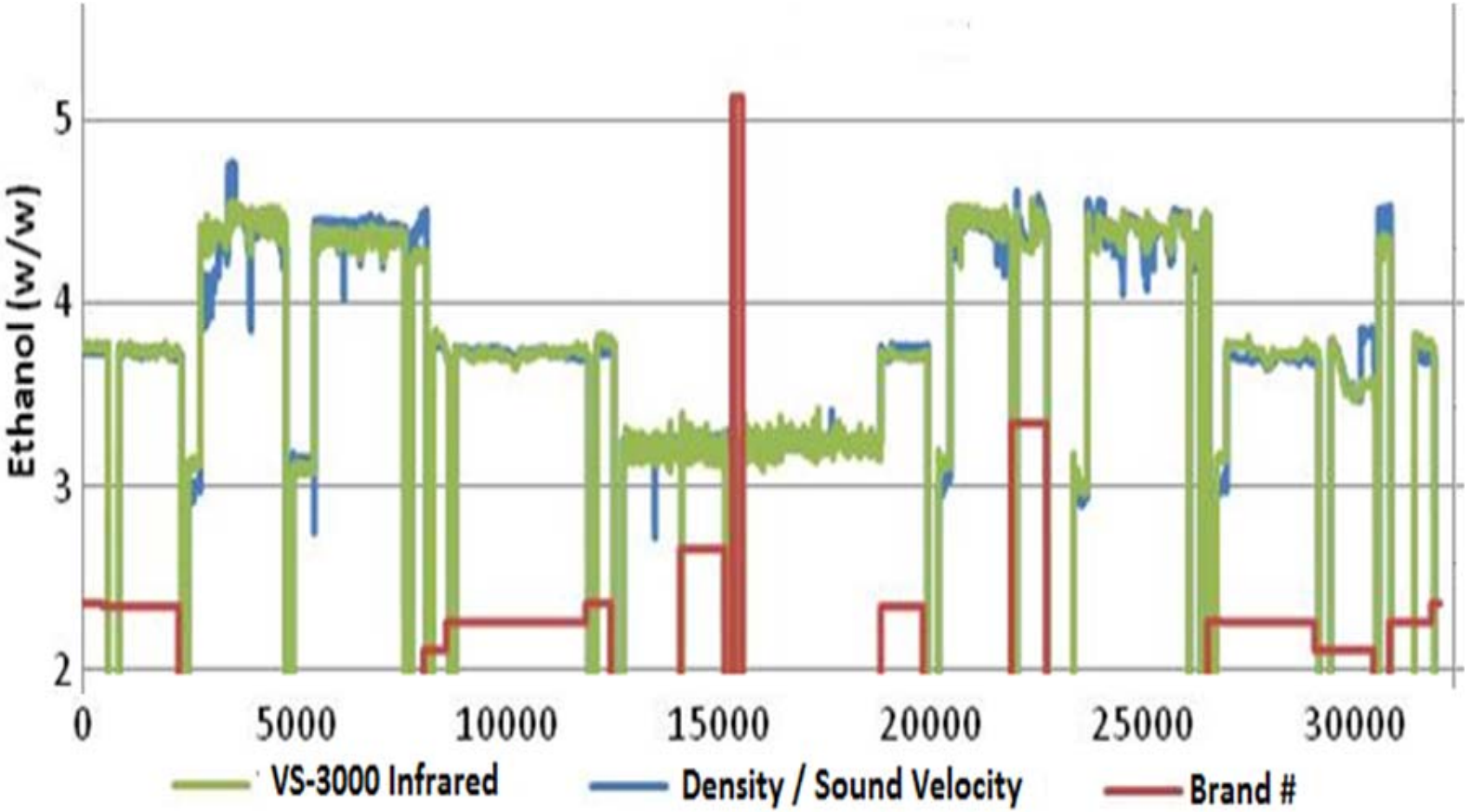
Mid-IR Sensors

Ethanol: MIRS vs. Density–Sound Velocity



Mid-IR Sensors

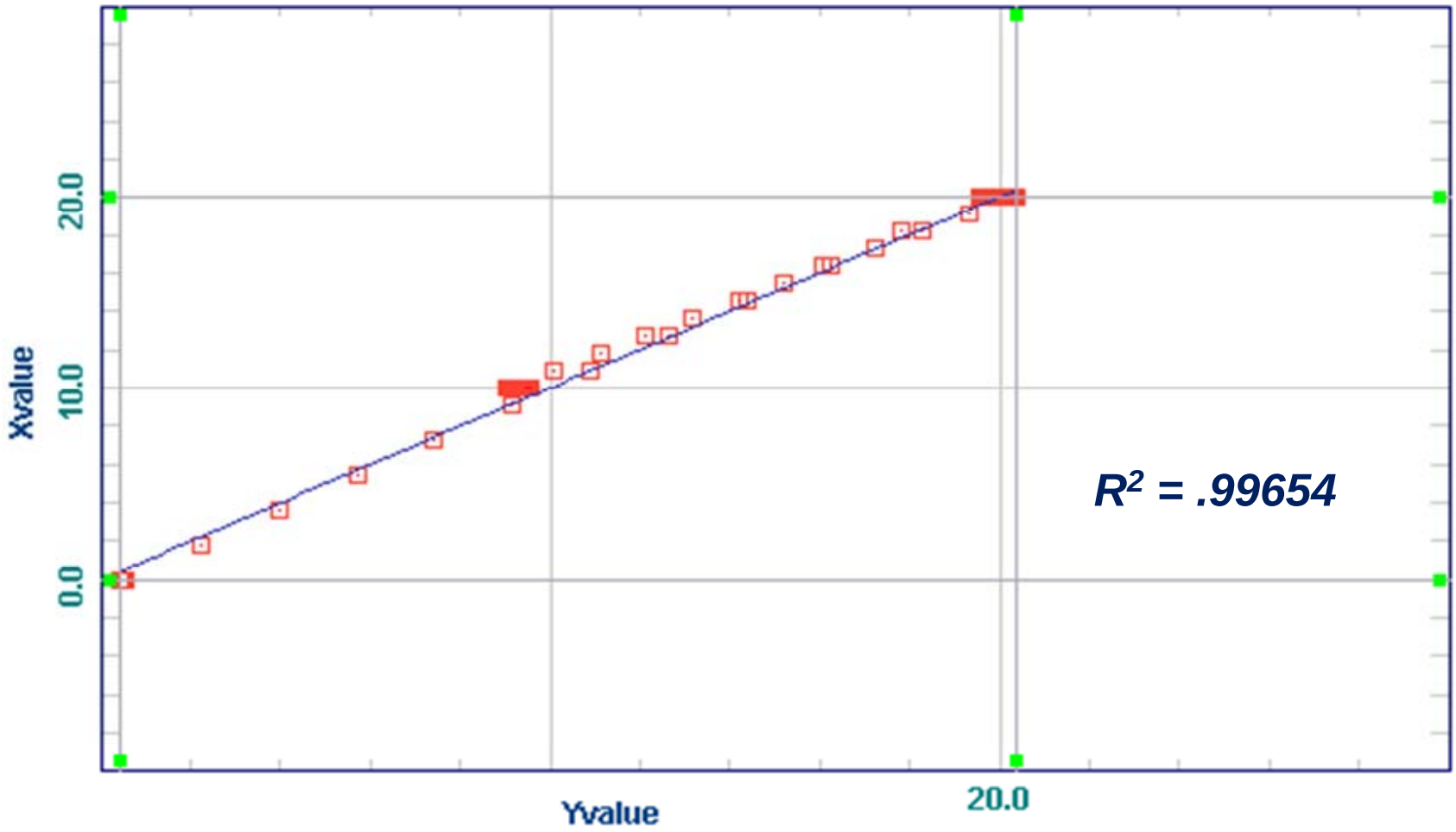
Ethanol: MIRS vs. Density–Sound Velocity



MIRS sensor used no offsets for this chart (37 brands), Density sound velocity had recipe parameters

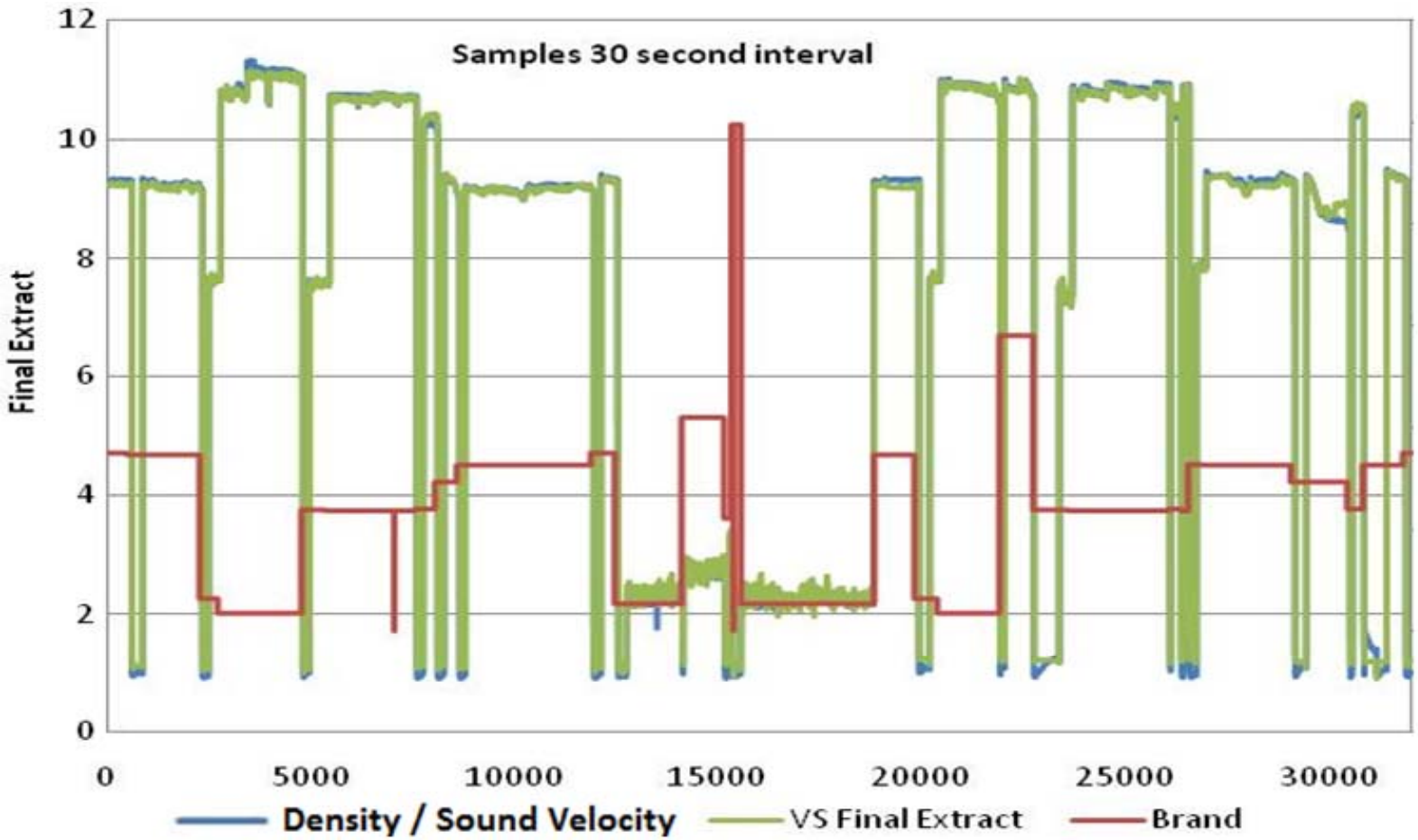
Mid-IR Sensors ***R^2 Confidence Level (Ethanol)***

MIRS Inline vs. Laboratory Instrument



Mid-IR Sensors

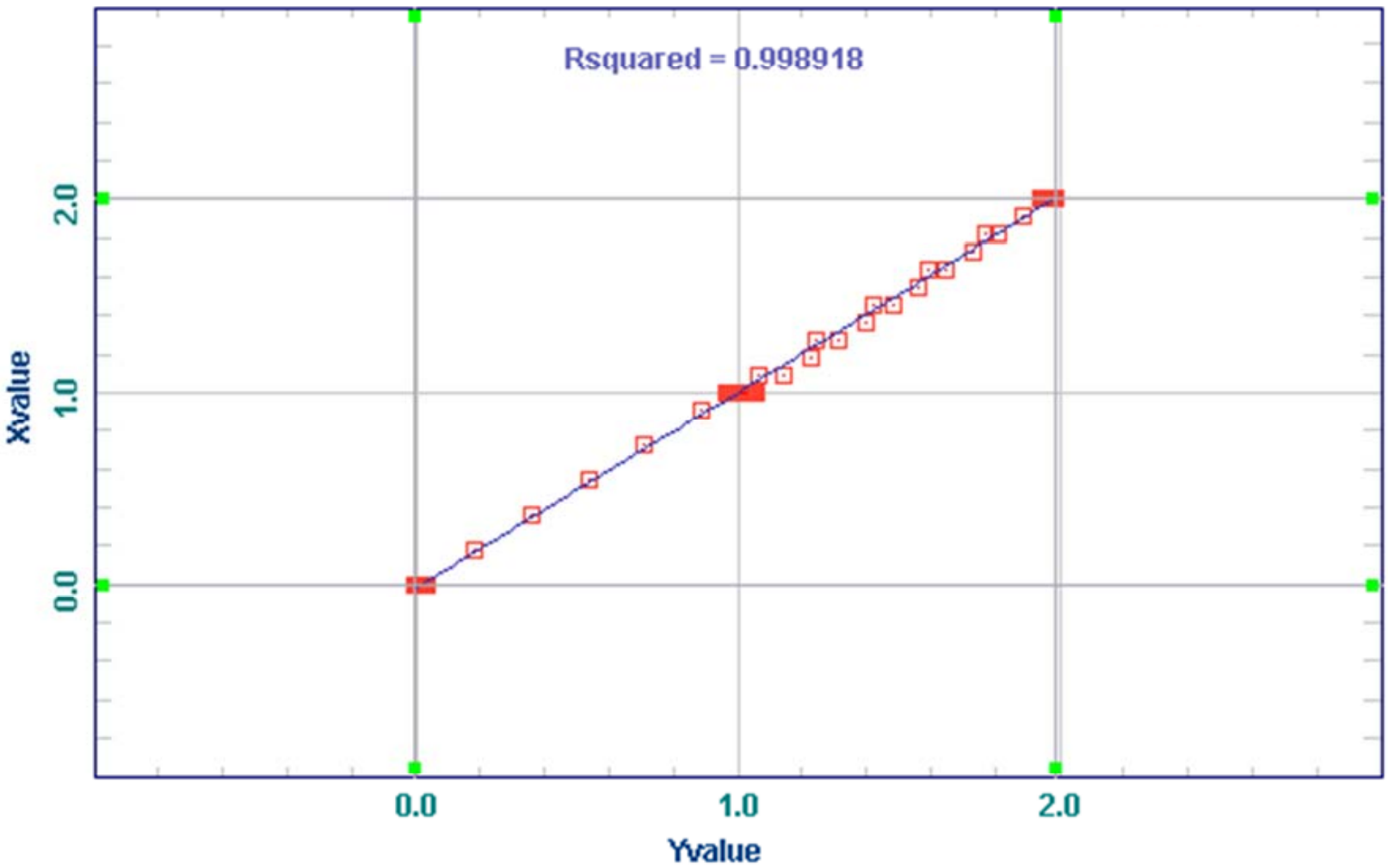
Real Extract (Er): MIRS vs. Density-Sound Velocity on a Bottling Line



- Very good correlation
- No recipe corrections for MIRS, Density-Sound Velocity meter is recipe corrected

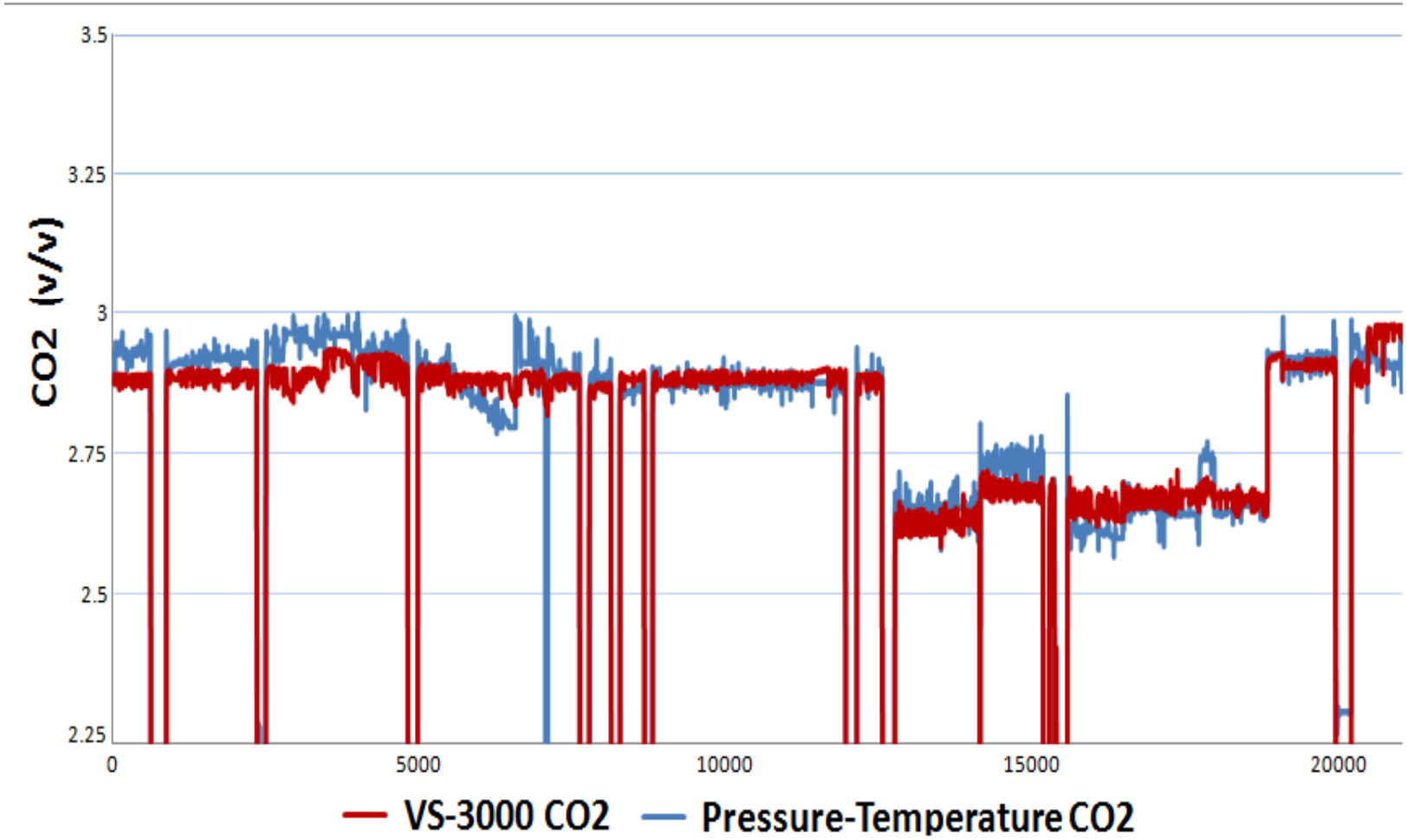
Mid-IR Sensors *R^2 Confidence Level (Real Extract)*

MIRS Inline vs. Laboratory Instrument



Mid-IR Sensors

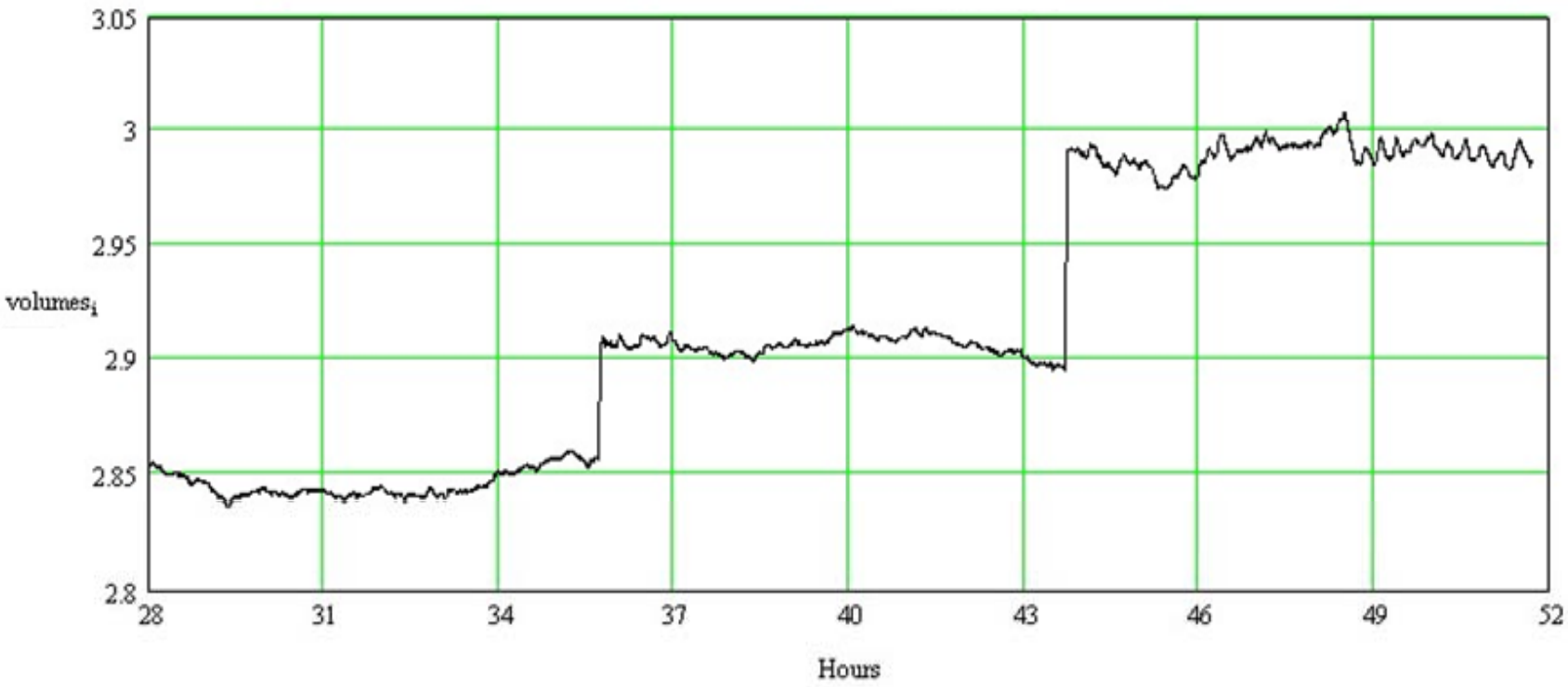
CO_2: MIRS vs. P-T on a bottling line



MIRS used no offsets for the 37 brands on this graph

Mid-IR Sensors

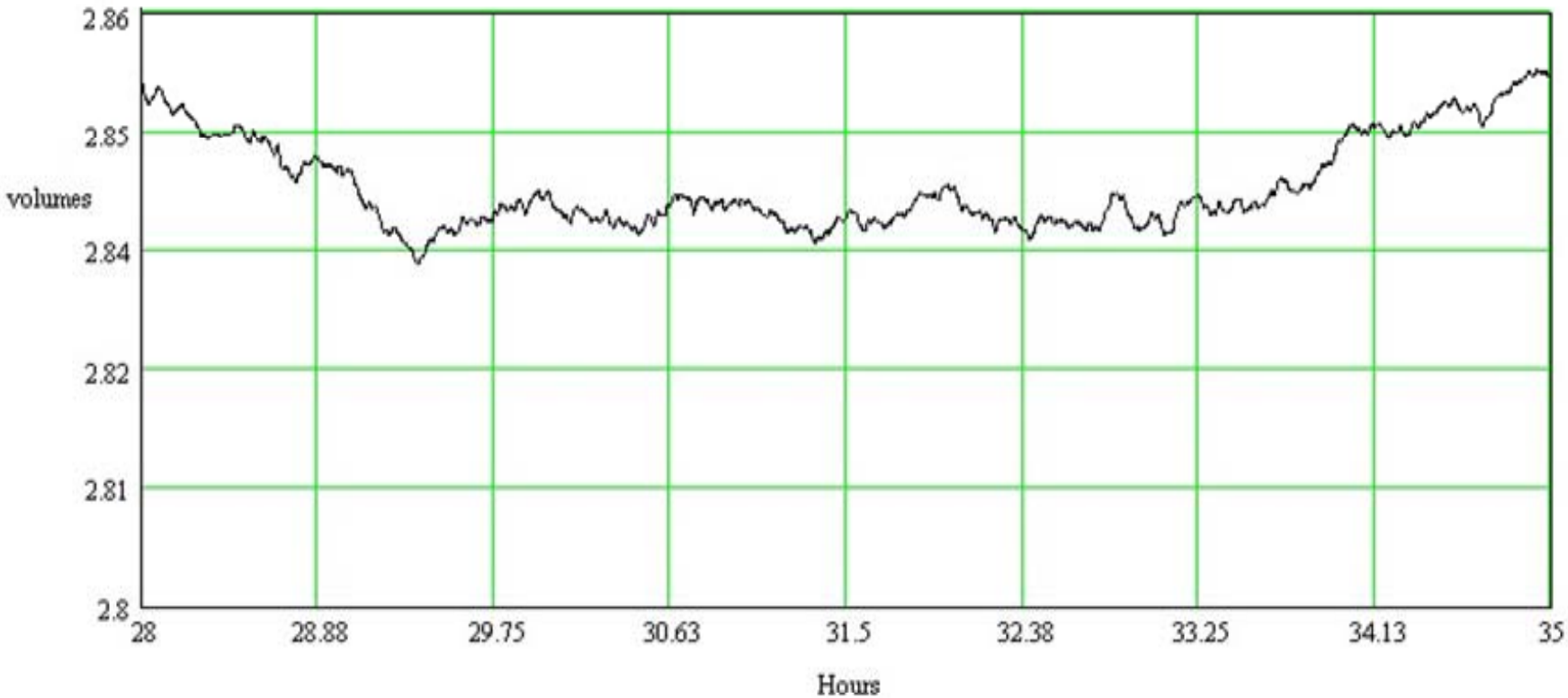
CO_2 Resolution Test



- Target Values: 2.84 volumes, 2.91 volumes, 3.0 Volumes
- Shows much better than .05 v/v resolution. Data shows better than .007 resolution
- 30°C Temperature Cycles
- 8 hour increments, data recorded every 10 seconds

Mid-IR Sensors

CO_2 Repeatability Test



- Data Repeatability: ± .008 volumes
- Target Value: 2.84 volumes; resolution better than .002 (v/v)
- 30°C temperature cycles show temperature immunity
- Data recorded every 8 seconds

Mid-IR Sensors

MIRS Form Factors

- Sensor available in a compact form factor compatible with either 68mm Tuchenhagen Varivent (left, *optimal*) or 1.5” Tri-Clamp (right, *option*)

- Construction material is 316L Stainless Steel, Certified for Dairy 3A Sanitary Standards, Max Pressure 150 PSI, Hermetically Sealed, IP68 Certified

Mid-IR Sensors *Fieldbus and Automation Options*

MIRS sensor head is controlled by the *Sensor Management Station (SMS)*

- Runs proprietary Windows-based embedded software on a PC-104
- Fieldbuses include EtherNetIP, 4-20mA (4 channel,16 bit) and standard Ethernet, Profibus DP is available as an option
- Customizable remote/relay alarms and brand change capabilities via DIO or fieldbus

Conclusions: Parameter vs. Ingredient Sensor

- Traditional instruments for inline measurements in breweries rely on outdated, approximation/inference methods; i.e., they measure parameters of the fluid rather than fluid ingredients.

- Ales, lagers, light beers and high gravity beer are incorrectly treated as identical for the purposes of Henry's Law and density/sound velocity measurements.

- Vibrational spectroscopy using Attenuated Total Reflection and Mid-IR eliminates shortcomings of traditional instruments.

Conclusions: Parameter vs. Ingredient Sensor

- MIRS instruments measure the true ingredients of interest to brewers i.e.. Ethanol, CO_2 and Real Extract (*Er*).

- MIRS instruments do not measure density, temperature, pressure or mass flow. These techniques measure parameters of beer, but not ingredients. Parameter methods are affected by gasses, valve changes, tank changes and pressure spikes; they require time consuming maintenance.

- Mid Infrared Sensors (MIRS) eliminate inference, approximation and maintenance, while providing resolution, accuracy and repeatability levels that were previously impossible to attain using parameter-based techniques rather than measuring product ingredients directly.

Mid-IR Sensors

MIRS Competitive Advantages

Feature	Function	Benefit
Mid IR Technology	Measuring method	- Direct repeatable measurement - Measures on molecular level - No hoses, U-tubes or pumps - Eliminate false production alarms
Solid State Device	Reliability	- No moving parts - High performance processor - Low cost of acquisition relative to alternatives - Instantaneous measurement 24x per second
Reduced user interactions	Unaffected by solids, density changes and color	- Fewer brand offsets compared to mechanical instruments - No sensor drift to check/adjust
Product Flow not required	IR technology does not require flow	- Sensor can be used on tanks, pipes or fillers - Anywhere where measured substance is dissolved

Mid-IR Sensors

MIRS Competitive Advantages

Feature	Function	Benefit
24x7 operation, Real-time data	Sensor designed to function continuously	- Continuous process monitoring with flow or no flow - Insensitive to pressure spikes or line changes
CIP and SIP Compatible	Sensor requires no special treatment	- Sensor functions during CIP and measures duration of events + temperature
Easy to Install	Sensor designed for use with standard flanges	- Low cost of installation and compact device - One sensor head measures multiple ingredients
Low Maintenance Device	Requires no routine maintenance	- Substantial maintenance hours savings - MTF > 100,000 hrs - Increased annual capacity and reduced down time

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