Rheonics SlurryTrack

Integrated solution for automatic slurry density/viscosity management in shell building

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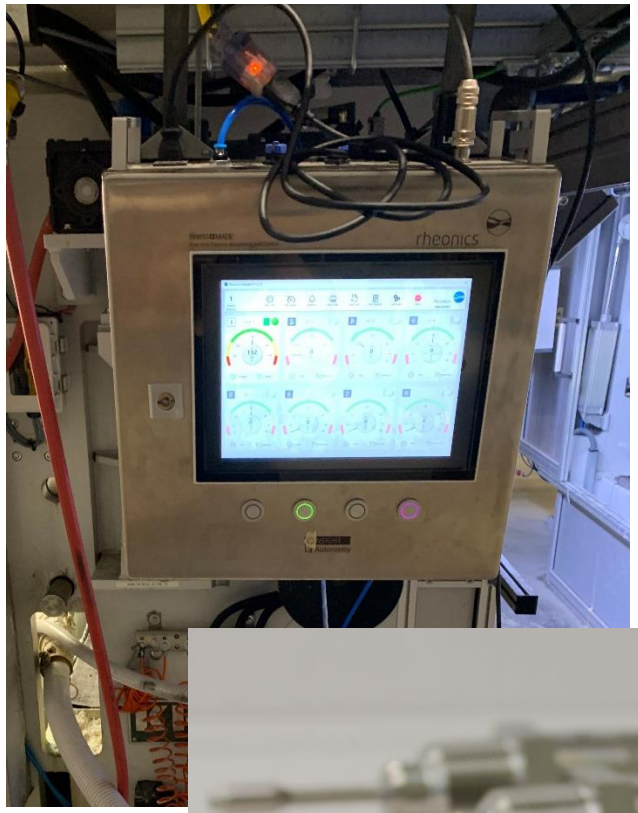
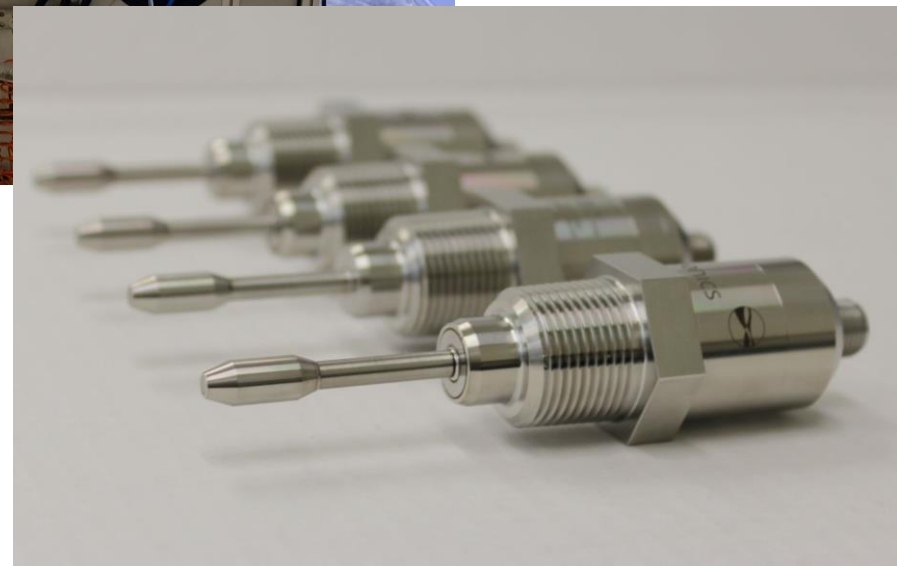
Rheonics - Introduction

- Rheonics was founded to solve the issue of lack of robust plug and play instruments for viscosity and density monitoring, two of the key physical properties of a process fluid.
- To achieve the vision of a no-hassle, easy to use inline viscometer, the founders brought together a team of experts from leading universities and global companies to build advanced intelligent fluid process monitoring instruments.
- Our sensors have been used by machine builders and fabricators for monitoring and controlling the quality of ceramic slurry. In investment casting, we see an application that has been on the look-out for a viscosity and density sensor that can help achieve the perfect dip coated parts for casting. Rheonics sensor met that need creating industry 4.0 enabled process optimization of the dip coating process.





Outline of the presentation

1. **Importance of viscosity and density for shell building**
   - Why slurry viscosity and density are important in shell building
   - An evaluation of traditional methods for controlling slurry viscosity and density
   - Factors affecting a viscosity/density measuring device selection for slurry application

2. **A reliable inline viscometer for slurry viscosity/density management**
   - Rheonics SRV/SRD viscometer/density meter as an alternative
   - Advantages of SRV/SRD for slurry viscosity/density management
   - Beyond measurement to real-time control

3. **Real-time slurry viscosity/density measurement and control in the shell room**
   - Sensor mounting options
   - Integrated solution: sensor, controller and control valves
   - A gateway to complete automation in shell building, Slurry Track = sensor + controller + software
   - Benefits for the users and technology outcomes for the industry

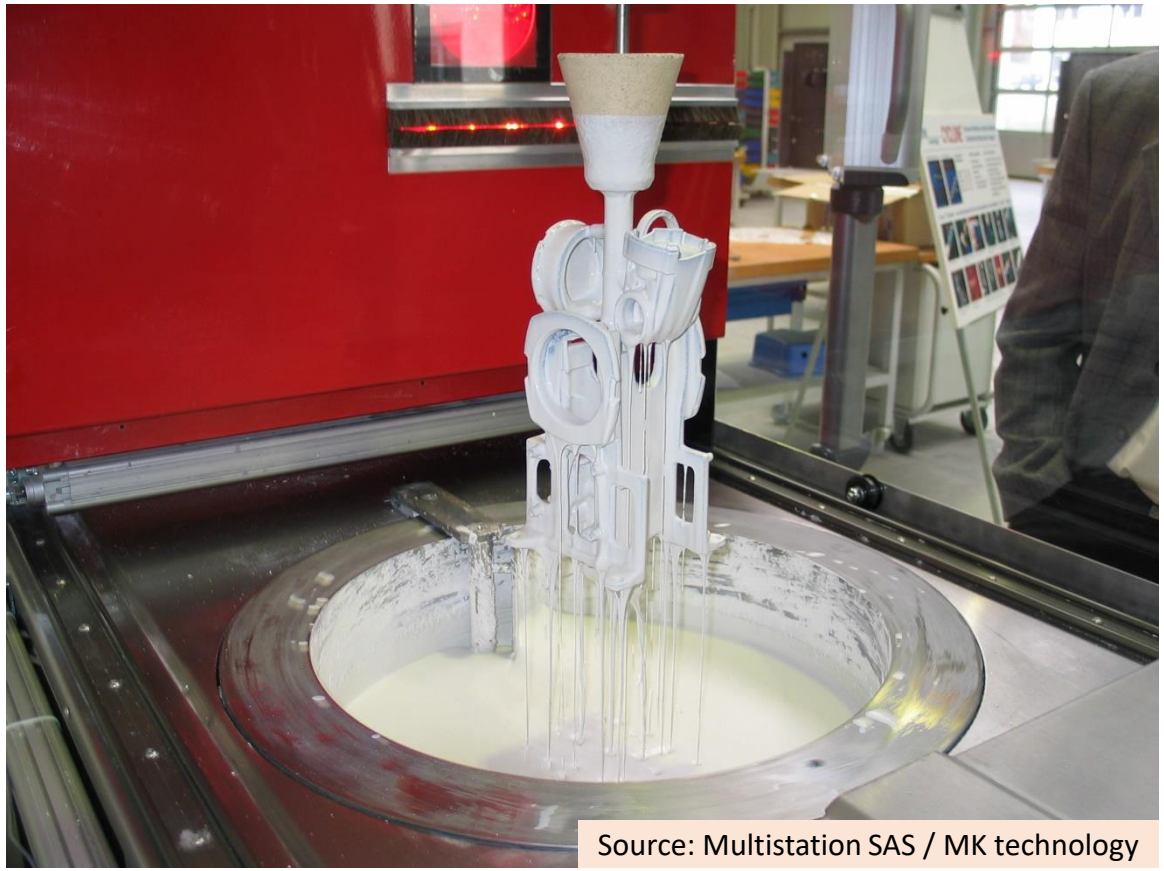
Part 1

Importance of viscosity and density for shell-building

- Why are slurry viscosity and density important in shell building?
- An evaluation of traditional methods for controlling slurry viscosity and density
- Factors affecting a viscosity/density measuring device selection for slurry application

Viscosity: Importance in shell building

- Measure of a fluid's resistance to flow
- Quantifies the thickness or thinness of a fluid
- Determines the thickness of the layer that remains after each dipping process
- Uniformity of the coated slurry layer on the wax assembly
- Tighter control of slurry viscosity has been found to contribute to the ease and quality of shell building, as well as the quality of the finished cast goods.

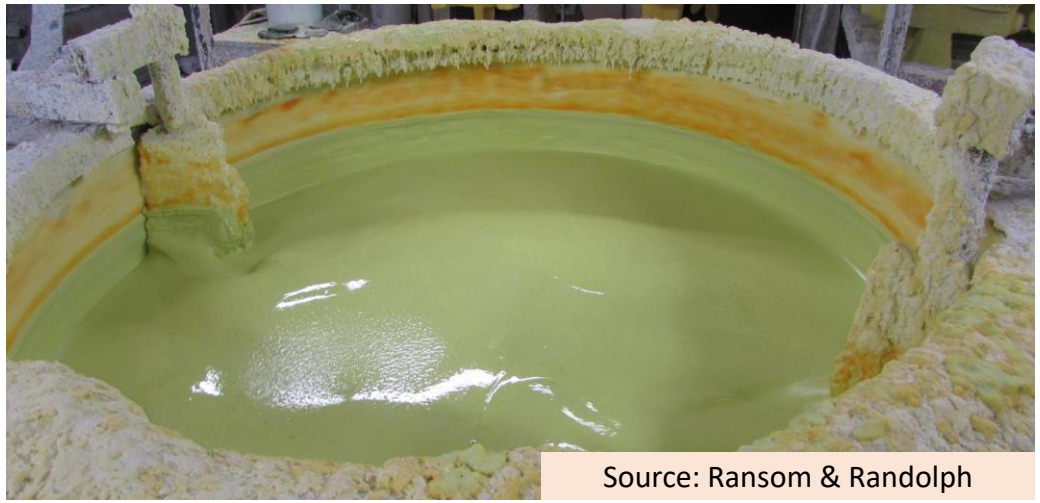


Source: Multistation SAS / MK technology

Slurry Viscosity and shell quality

- A good slurry composition alone cannot guarantee production of smooth and defect free shell if the slurry is prepared in an inadequate manner.
- It is an important determinant of the ***layer thickness and adhesion***, i.e. how much of it will remain on the wax assembly during the dipping and draining cycles.
- Solids loading also affects shell thickness and quality, best determined from slurry density (weight)

Source: ICI / investmentcasting.org



Source: Ransom & Randolph

Shell properties affected by slurry viscosity and density

Several literature and studies to investigate the effect of controllable shell building process variables on the shell properties cited viscosity as an important input variable.

Shell properties affected by viscosity and density of the slurry:

- Layer & final thickness
- Surface finish
- Permeability
- Strength
- Edge coverage
- Edge strength
- Bending strength
- Thermal characteristics

Shell defects that are caused by improper slurry viscosity

Slurry Preparation Problems:

1. Penetration
2. Buckle
3. Bubbles

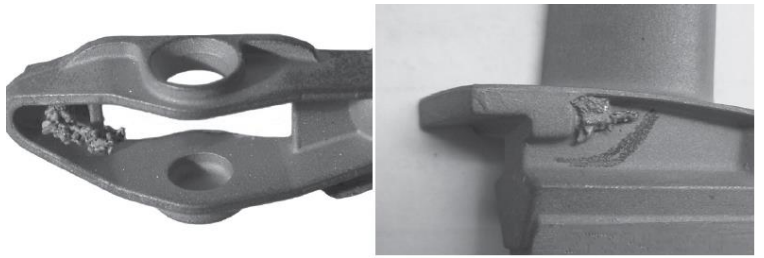
Slurry Maintenance Problems:

4. Excess Metal/ Bridging effects

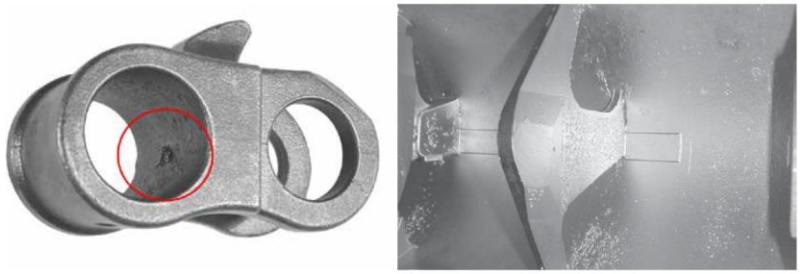
Shell Drying Problems:

5. Spall

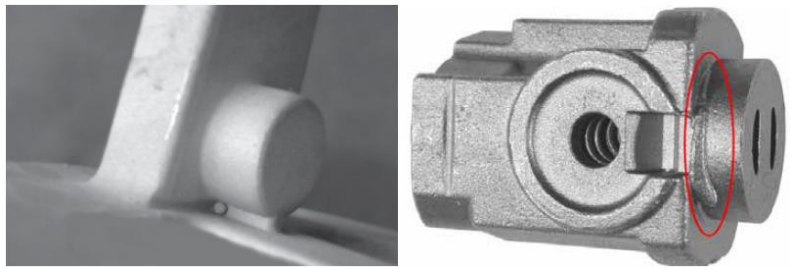
Buckle



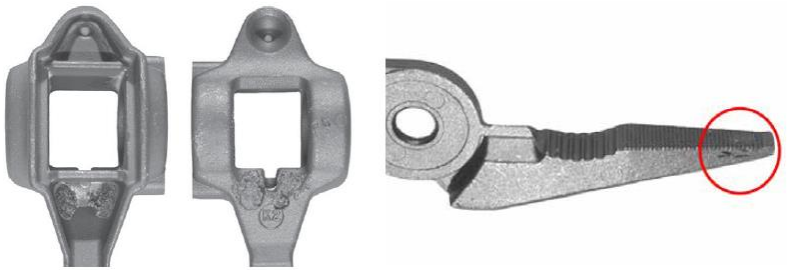
Excess Metal



Penetration



Bubbles



Spall

Source:
Atlas of Casting Defects, An Investment Casting Institute Publication, December 2017
Atlas of Shell Defects, An Investment Casting Institute Publication, February 2004

Requirements from a viscosity/density monitoring device from the casters' perspective

The search for viscometer/density meter for slurry applications has been long, with researchers highlighting key requirements:

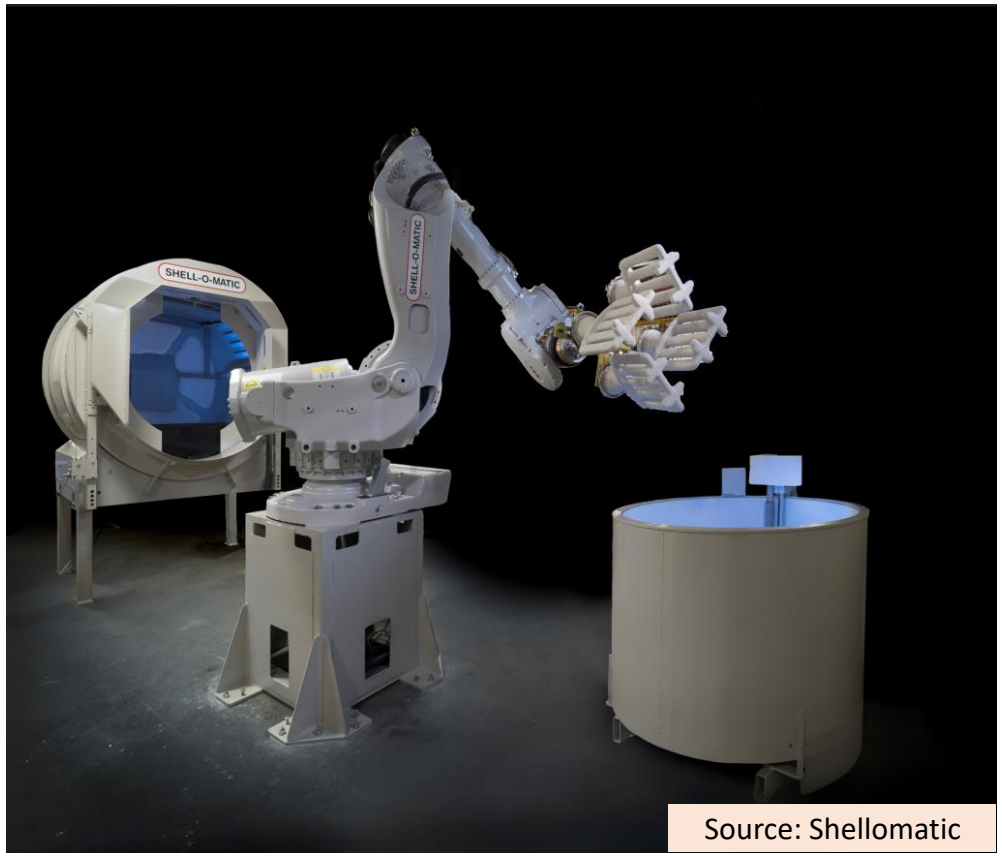
- Takes **continuous measurements** of actual viscosity and density during shell forming process
- **Avoid delay** for sampling and evaluation of measurements
- Requires **no calibration**
- Should be "transparent" to the **operator**, requiring no special knowledge, operation, or evaluation of results
- Should provide measurements that can be used by **automation** of processes

Current methods for viscosity and density measurement

Despite their importance to shell quality, slurry viscosity and density are still measured by centuries-old methods that interface poorly with emergent Industry 4.0 standards.

Current methods require manual sampling and testing.

Rheonics SRV/SRD and **SlurryTrack technology** offer a simple and efficient bridge to bring slurry management up to the modern standards that prevail in today's highly automated shell rooms.



Source: Shellomatic

Showing the installation of the Rheonics SRV viscometer in a shell building slurry drum

Traditional methods and their limitations

Slurry viscosity is still measured by old methods. The involve manual sampling and testing in laboratories, two main methods are:

- Efflux cups
- Rotational viscometers

Slurry density is measured by weighing a sample with known volume to get the slurry weight

Limitations

- Offline, needs sampling
- Need experienced operators
- Can’t supply the data needed for inline process control

Source: Gardco

Source: Brookfield

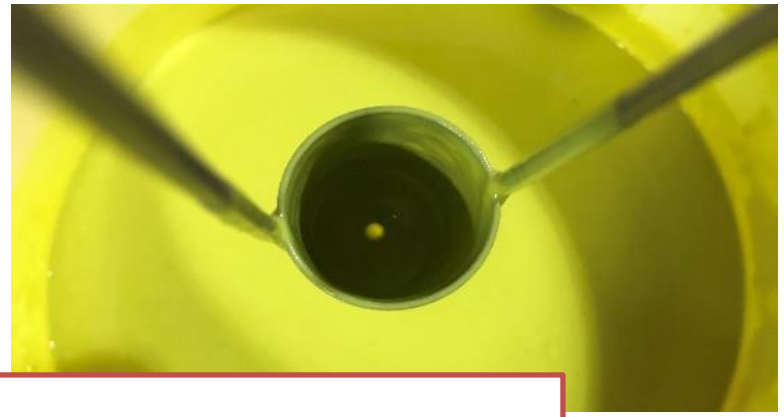
Source: Ransom & Randolph

Are cups suitable for viscosity checks?

- Accuracy issues
- Cleaning issues
- Frequent calibration with a standard DIN cup
- Slurry viscosity in ‘cup seconds’

Source: Ransom & Randolph

- Where do you dip the cup in the tank?
- How do you store the data and do long-term optimizations
- When do you start and stop recording the time?
- Non-repeatable even with experienced operators



The many uncertainties in procedures, as well as wear and deposits on cups, contribute to less than optimal accuracy and repeatability of cup measurements

Is volumetric weight suitable for density measurements?

- Accuracy issues
- Cleaning issues
- Messy
- One-point measurement, sample doesn't necessarily reflect bulk density in tank
- Where do you dip the cup in the tank?
- How do you store the data and do long-term optimizations
- When do you start and stop recording the time?
- Non-repeatable even with experienced operators

Source: Ransom & Rndolph

Rotational viscometers and rheometers: Limitations of lab measurements

- Measurements **cannot** be made under actual use conditions
- Affected by temperature, shear rate, humidity and other variables
- Difficult to decide what parameters are relevant
- Necessary sampling rates not well established
- Issues with repeatability and reproducibility
- How do you store the data and do long-term optimizations?

Source: Gradco/Brookfield

Delay between measurement and action:

Source: IPCL India

Sample collected from slurry tank sent to lab for analysis

Elapsed time = ?

Source: Brookfield

Suitability of traditional measurements for shell room use

- None of these methods is easily adaptable to real-time, inline control of slurry viscosity
- Measurements must be recorded manually into the automation processes involved
- Rotational viscometers need labs for analysis.
- By the time the laboratory reports on the sample, it no longer reflects the actual slurry condition in tank
- Volumetric weighing has similar limitations as traditional viscosity measurements

Summary: Limitations of offline measurement techniques

- **Efflux cups:**
  - **Inaccurate:** depend on the operator's judgement. Repeatability is seldom under 1 seconds.
  - **No temperature control :** although viscosity is highly temperature-dependent.
- **Rotational viscometers:**
  - **Rely on operators' expertise:** Lab viscometers are delicate, and require skilled operators
  - **Not a real-time indicator of slurry in the process:** Samples sent to the lab are not the same as the material currently in the slurry tank, since the measurement may be made hours after the sample is drawn.

Neither method is readily adaptable to inline, real-time viscosity control. Measurements must be recorded by hand, and then entered into data processing and control systems

Vibrational Instruments – Reliable alternatives?

Advantages	• Can be mounted in the slurry drum directly • Real-time behaviour of the slurry can be monitored • Do not rely on operator's expertise
Limitations of current products	• Frequent calibration required • Difficult to set up and maintain • Many are sensitive to outer vibrations and shocks • Large size and mass makes them difficult to mount, and susceptible to damage through inadvertent contact with surrounding equipment

Source: Sofraser, Hydramotion, Nametre (GAS)

Desirable features of a shell room viscometer

- Inline sensor to make direct viscosity and density measurements on the ceramic slurry
- Does not require re-calibration and must be easily cleanable
- Provides repeatable measurements – to support process quality as well as information for process improvement
- Fast, reliable response to slurry viscosity changes to enable immediate operator intervention if necessary
- Produces log of viscosity and density data and an intuitive interface (software) to visualize the process data
- Enable viscosity and/or density control automation in shell rooms, to keep pace with the already high degree of process automation
- Provide a path to full shell-room automation

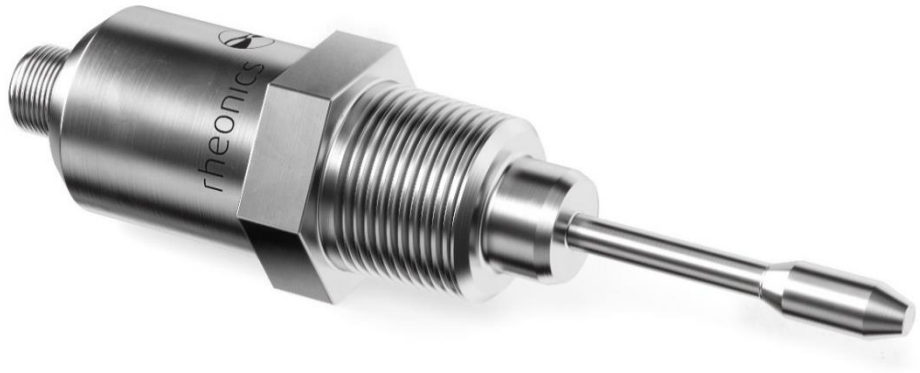
Part 2

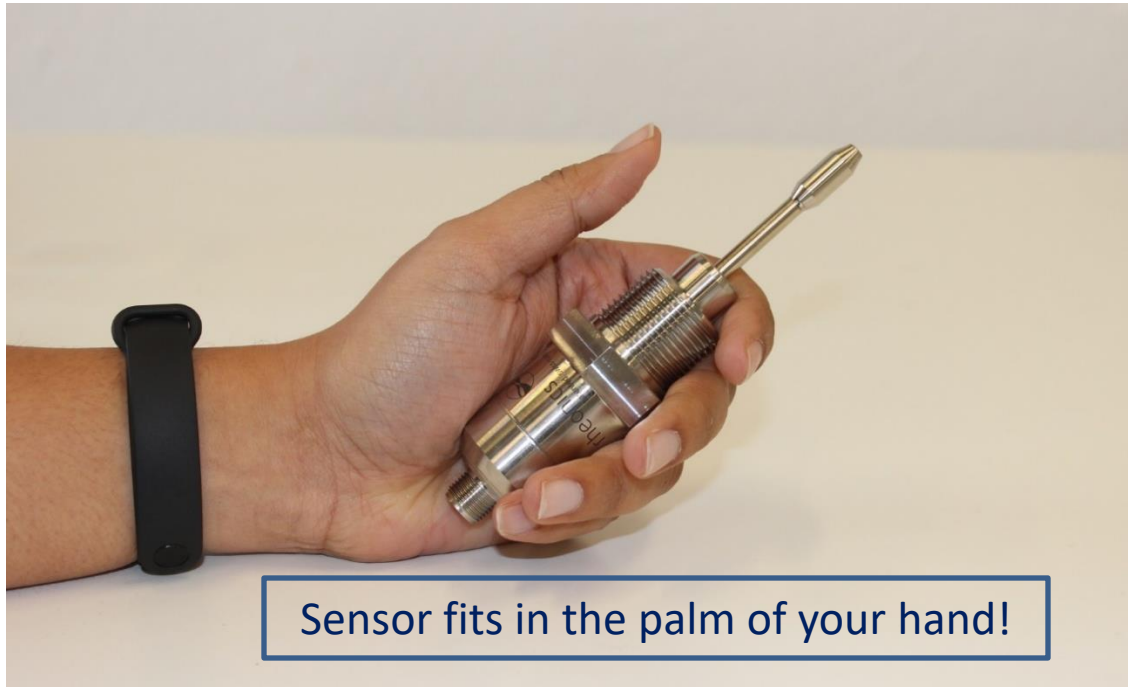
A reliable inline viscometer/density meter for slurry viscosity management

- Rheonics SRV viscometer as an alternative
- Rheonics SRD offers viscosity and density in one instrument
- Advantages of SRV/SRD for slurry viscosity and density management
- Beyond measurement to real-time control

Rheonics SRV: The viscosity technology revolution for this application

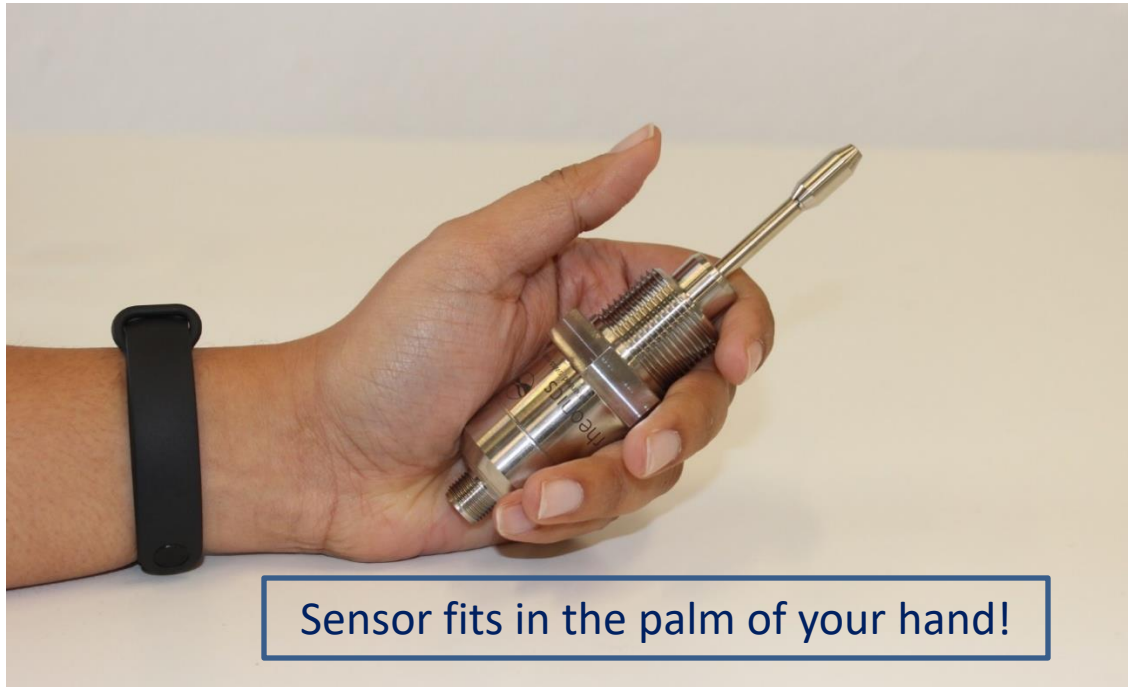
- Inline viscometer measures slurry viscosity in the drum: No sampling!
- Compact form for easy, unobtrusive installation
- Wide measurement range – works with slurry of any viscosity
- Extremely repeatable measurements
- Responsive, stable measurements – not influenced by shocks or vibrations during operation





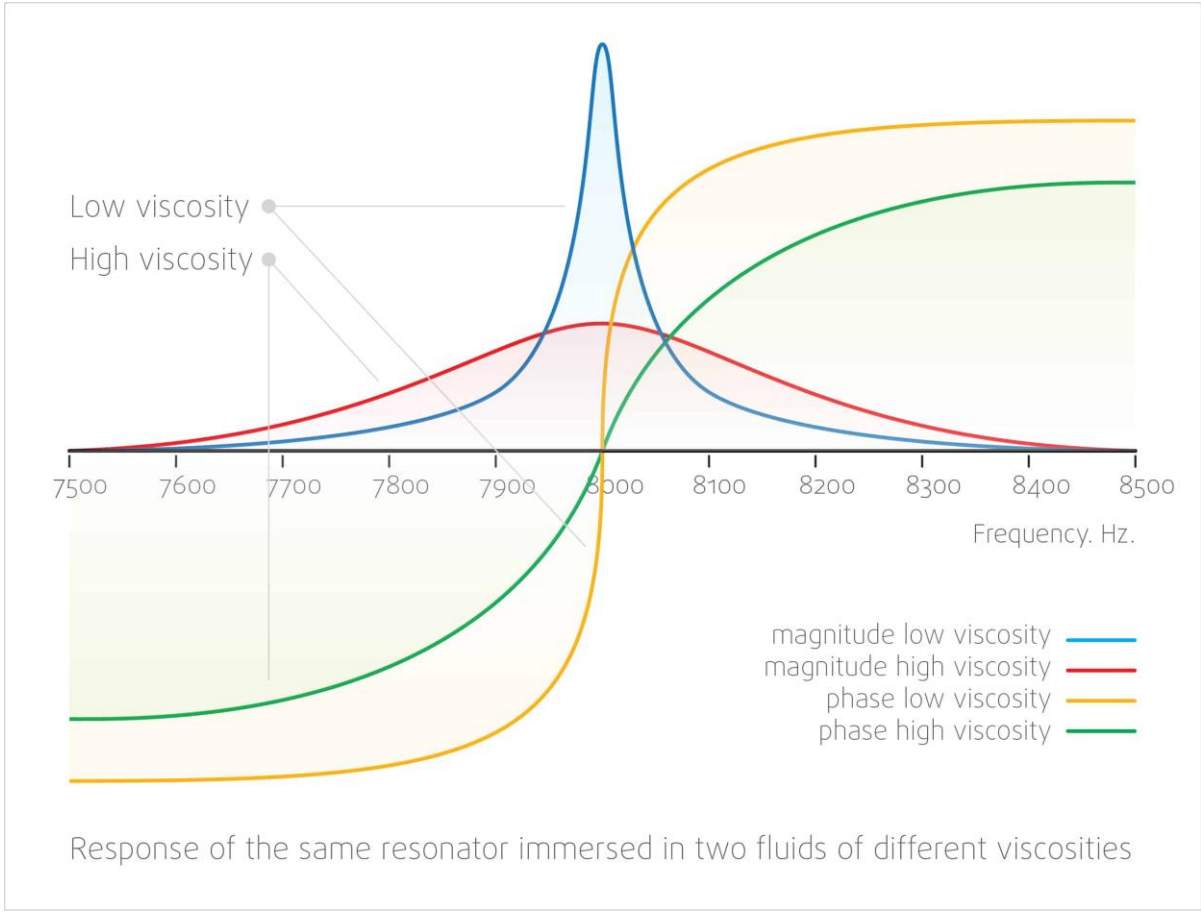
Rheonics SRD: The viscosity *and* density technology revolution for this application

- One inline instrument measures both density and viscosity in the drum: No sampling!
- Same compact form as SRV for easy, unobtrusive installation
- Wide measurement range – works with slurry of any density and viscosity
- Extremely repeatable measurements
- Responsive, stable measurements – not influenced by shocks or vibrations during operation



Balanced Torsional Resonator: The game changer in viscometer technology

- Rheonics SRV/SRD viscosity technology makes use of an ultra-stable torsionally balanced mechanical resonator (US patent 9,267,872) whose oscillations are damped by the viscosity of the slurry.
- The more viscous the fluid, the higher the mechanical damping of the resonator. By measuring the damping, the product of viscosity and density is estimated.
- The resonator is excited and sensed by means of an electromagnetic transducer mounted in the sensor's body.
- Damping is measured by Rheonics patented gated phase-locked loop technology .
- Based on these two key technologies, the SRV viscosity sensor delivers stable, repeatable and highly accurate measurements.



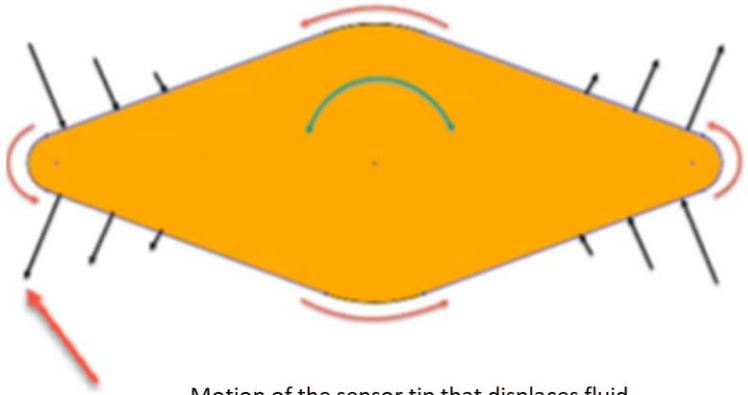
Sensor Operating Principle

Read more: https://rheonics.com/whitepapers/

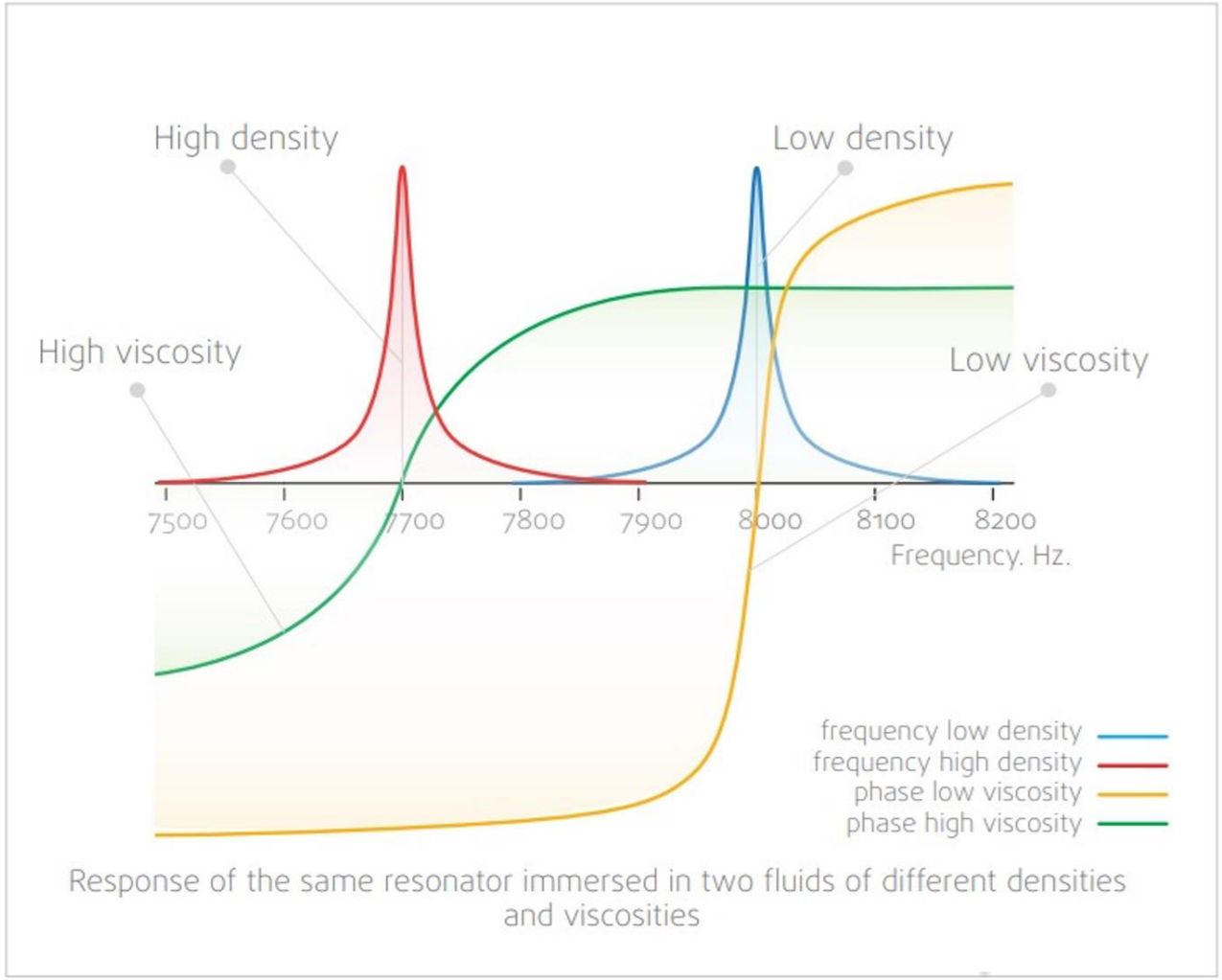
SRD adds density functionality to slurry viscosity measurement

- SRD measures viscosity similarly to SRV
- In addition, the unique shape of the sensor tip makes SRD sensitive to density – higher density lowers the resonance frequency of the sensor
- Based on similar technology, the SRD viscosity and density sensor delivers stable, repeatable and highly accurate measurements.

Vibration of the SRD tip showing both tangential and perpendicular motion



Motion of the sensor tip that displaces fluid



Response of the same resonator immersed in two fluids of different densities and viscosities

Sensor Operating Principle

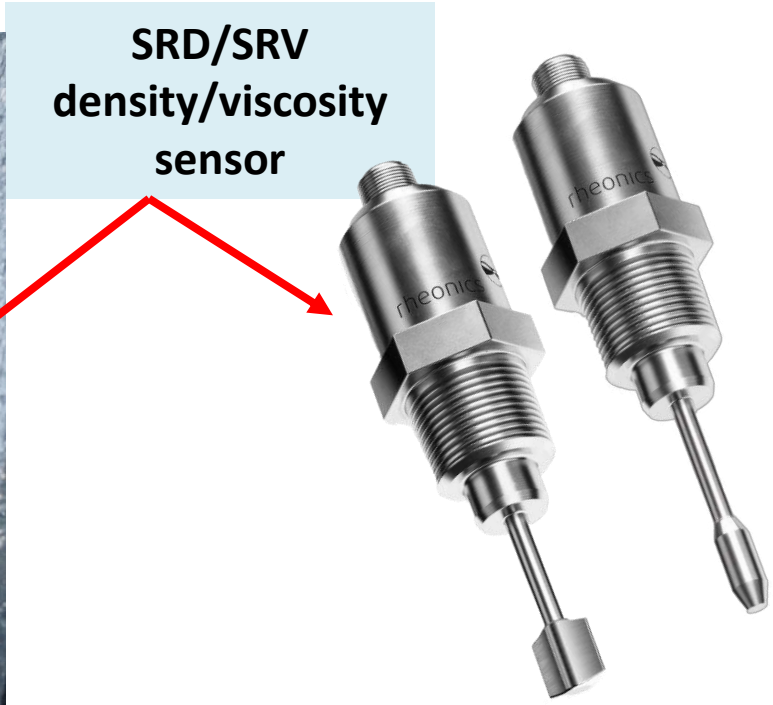
Read more: https://rheonics.com/whitepapers/

Rheonics SRV: Revolutionizing slurry viscosity and density control in shell room

Source: Digital Fire

The traditional way

Measuring viscosity with cups is unreliable, inaccurate, time-intensive even with experienced operators.



The Autonomous way:
Continuous viscosity monitoring by Rheonics SRV viscometer

- No operator intervention required
- Measurement is continuous, without having to worry about sampling or accuracy
- The SRV sensor provides 1 reading per second!

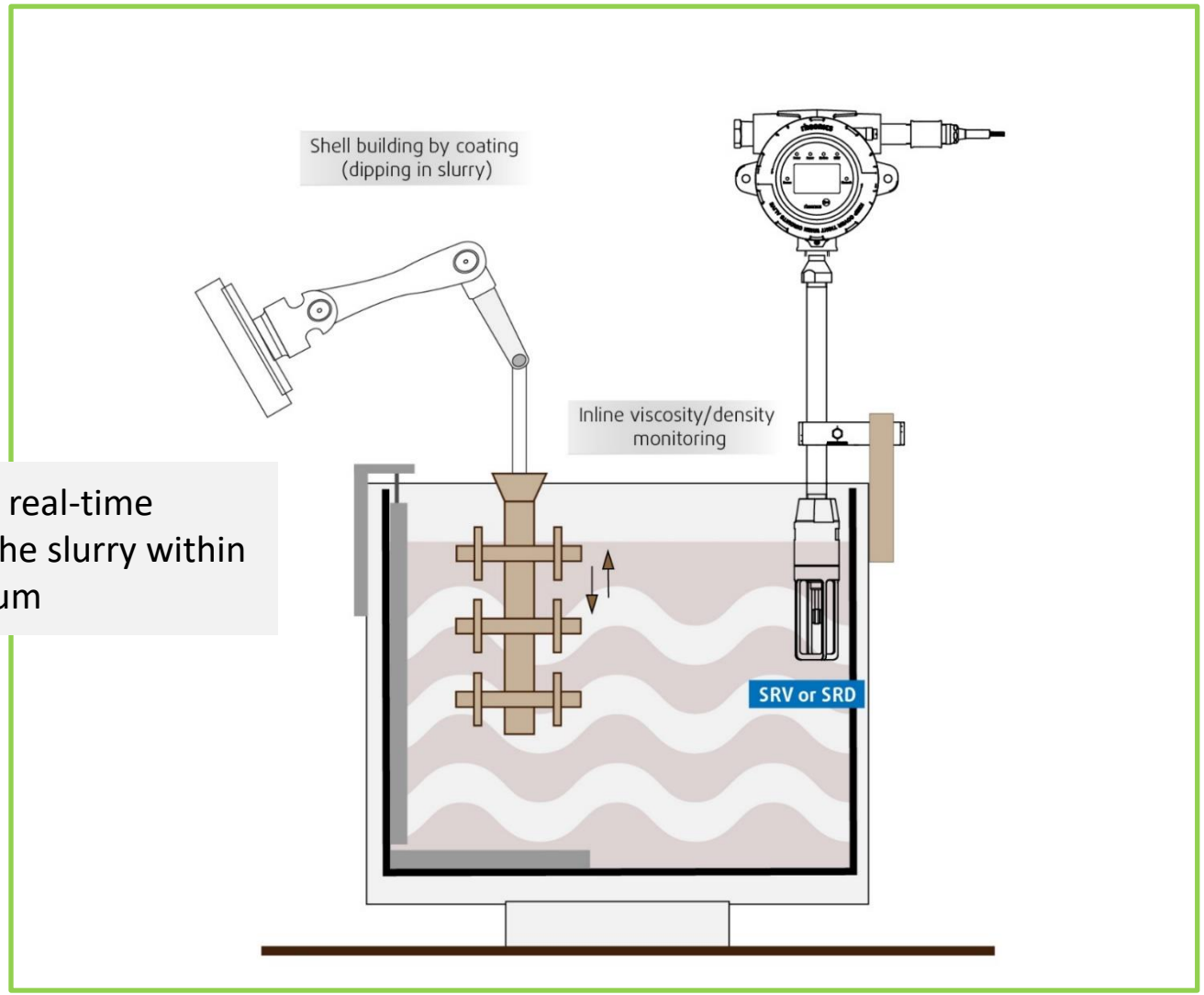
Long delay: Slurry in drum may no longer have same properties as sample

Sample collected from slurry tank sent to lab for analysis

Elapsed time may be hours

No delay : Reads the actual viscosity and density of the slurry in the drum

Directly make real-time measurements on the slurry within the drum



SRV and SRD– Truly revolutionary technology for slurry quality control

- ***No more manual handling or offline sampling of slurry:*** Replaces cup measurements and offline lab measurements.
- ***Independent of operators skills or judgement***
- ***Sensor needs no re-calibration, cleaning or maintenance:*** Sensor is permanently calibrated and maintenance free over the expected 25 years lifetime of the sensor.
- ***Extremely dependable and reliable data:*** SRV/SRD's viscosity/density data is extremely repeatable and reproducible. Operators can fully the viscosity data (trends, changes, disturbances) for making process decisions, reliably and dependably.
- ***Provides a direct, stable link between slurry viscosity/density and casting quality:*** Operators can focus the shell building job instead of slurry measurements.
- ***Works with all types of slurries:*** SRV/SRD works reliably with all slurry types and coats. Same accuracy and reliability over whole viscosity range.
- ***Built-in temperature monitoring enables temperature compensation of viscosity***

SRV – Build it into the machine instead of building the machine around it

- SRV/SRD's ***compact form factor*** means lower footprint and easy integration in the slurry drum.
- ***Simple sensor integration*** reduces installation cost.
- ***Measurements are unaffected by vibrations***, temperature variations or shell room machinery.

SRV/SRD – Typical use case inside the shell room

- SRV shows when slurry is getting thicker due to evaporation.
- SRD shows when solids content needs correction
- Operator compensates adding diluent.
- SRV/SRD shows trend of slurry viscosity/density – helps predict problems before they happen. Operator can take corrective action if properties deviate from control limits.
- Displays and logs viscosity data. Log can be used for analyzing the slurry and supporting data-driven quality improvements.
- Measurements available in digital form, so viscosity/density can be recorded and entered into the factory automation system without human intervention.

Showing the installation of the Rheonics SRV viscometer in a shell building slurry drum

SRV with tank mount adapter: Rugged sensor made for tough environments

SRV/SRD is provided with a tank mount adapter that allows quick install in the drum and prevents damaging its sensing element through inadvertent impacts with other equipment, as well as with unmixed clumps of slurry ingredients.

SRV's tank mount adapter components

The SRV/SRD with its tank mount adapter are installed in the slurry tank, with a cable connecting it to the SlurryTrack system.

SRV hooked to tank mount adapter for installation in slurry drum

Part 3

Real-time slurry viscosity and density management for shell building

- Sensor system installation options
- Integrated solution: sensor, controller and control valves
- A gateway to complete viscosity/density automation in shell building, Slurry Track = sensor + controller + software

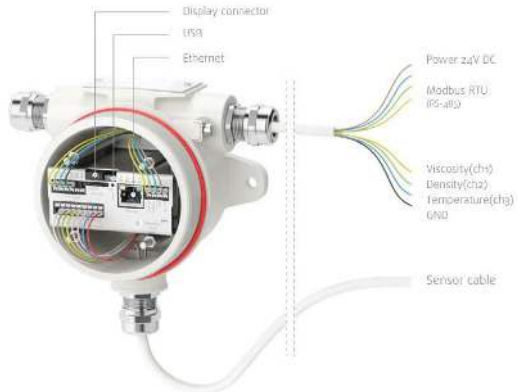
SRV installed to autonomously monitor viscosity with built-in display

1. Install sensor in slurry drum

Install SRV/SRD probe in slurry tank using tank mount adapter

2. Connect sensor to electronics

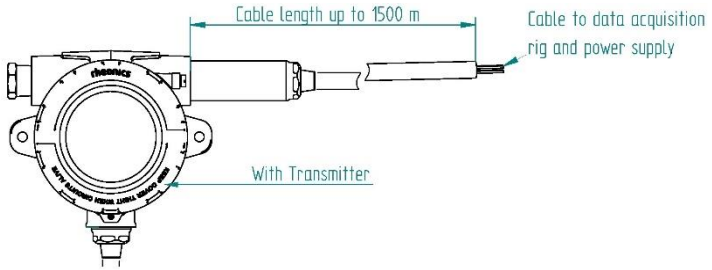
Connect SRV/SRD probe to sensor electronics. Power electronics.



SRV/SRD electronics with built-in display

SRV electronics can be wired to customer's PLC for viscosity control

3. Connect sensor electronics to PLC

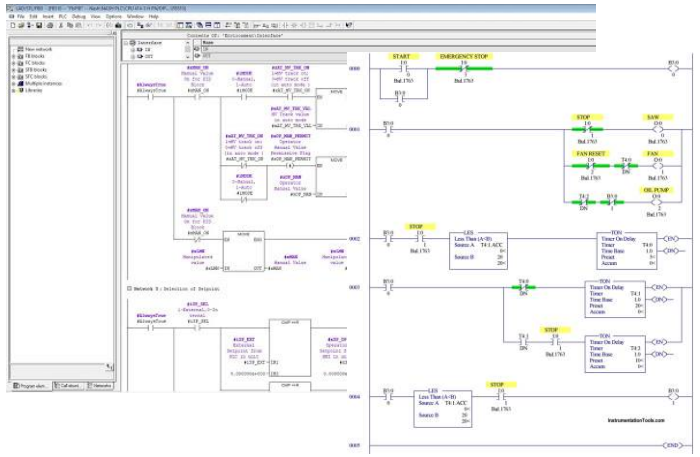


Connect using:

- 4-20mA
- Modbus
- Ethernet IP

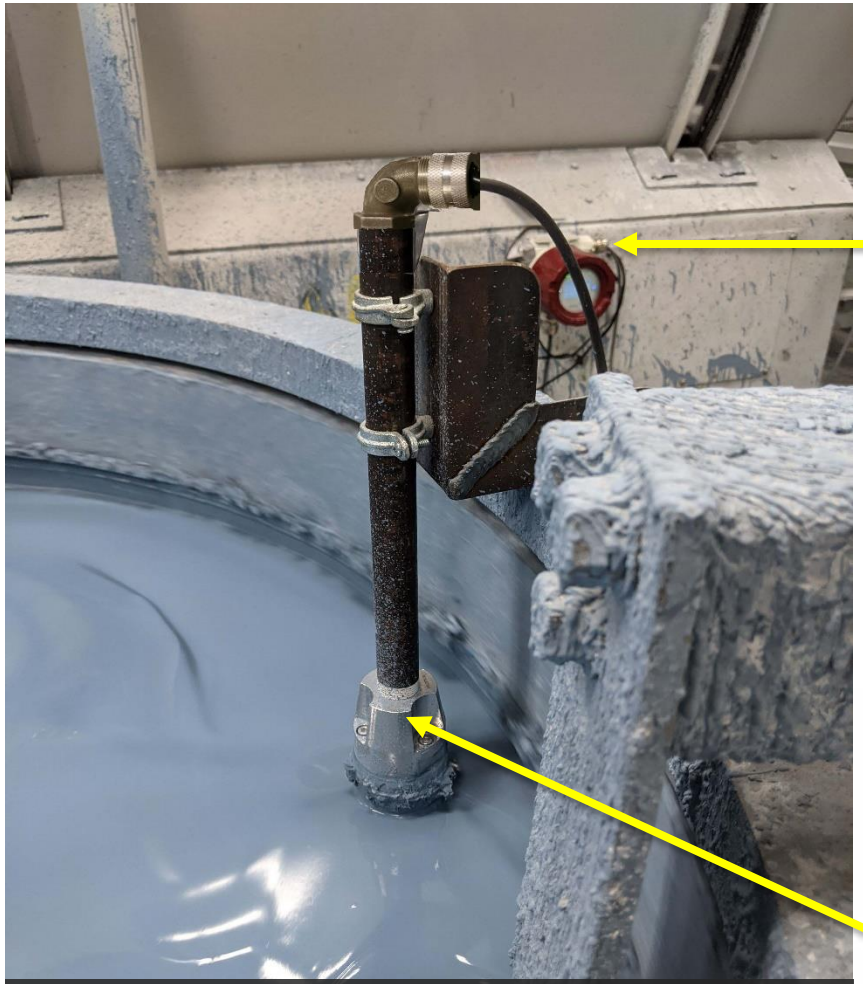
Customer PLC

4. Program PLC to monitor and control viscosity/density



Generally performed by customer automation engineers

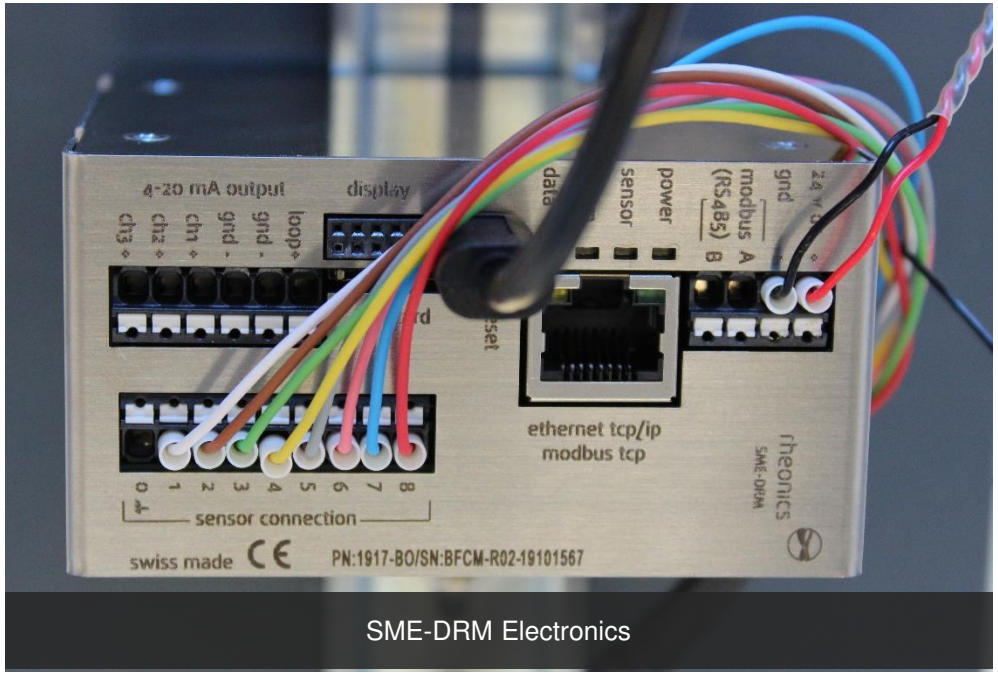
SRV/SRD is connected to remote electronics by a cable



Showing the installation of the Rheonics SRV viscometer in a shell building slurry drum

Electronics (SME-TRD)

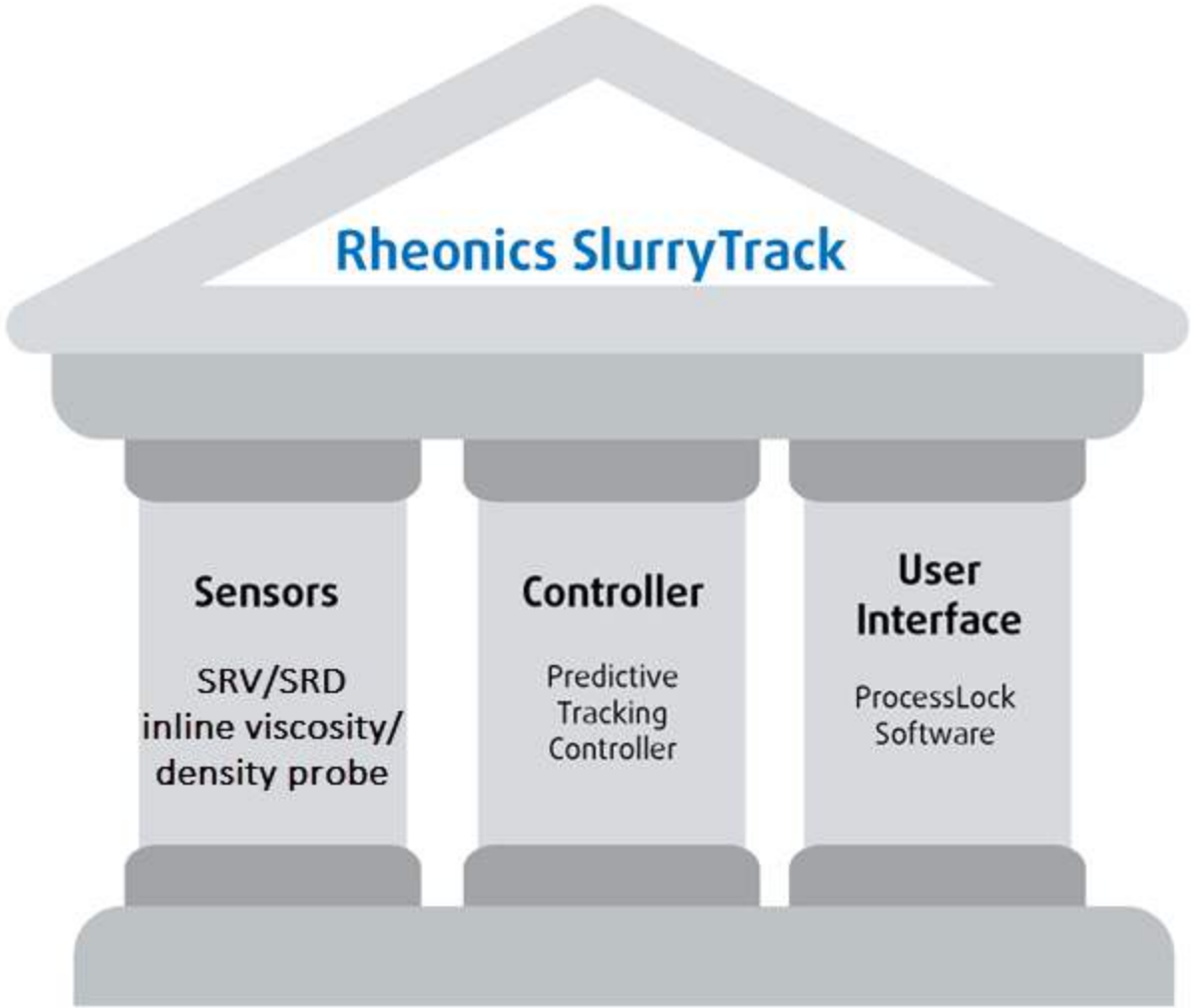
SRV/SRD Viscosity/density probe



SME-DRM Electronics

The SRV/SRD is connected to the SME-DRM electronics, which is connected to the customer PLC (using 4-20mA channels).

Full system integration for monitoring and control: Rheonics SlurryTrack



Rheonics SlurryTrack for monitoring and control

Rheonics **SRV/SRD Sensor** with its *tank mount adapter* is directly mounted on the slurry tank/drum.

MEASURE

SlurryTrack predictive tracking controller that receives the SRV/SRD's viscosity/density measurement, compares it to the viscosity set point, and actuates a **solenoid valve** that doses diluent–typically water–into the slurry tank/drum to restore it to the set viscosity or density

CONTROL

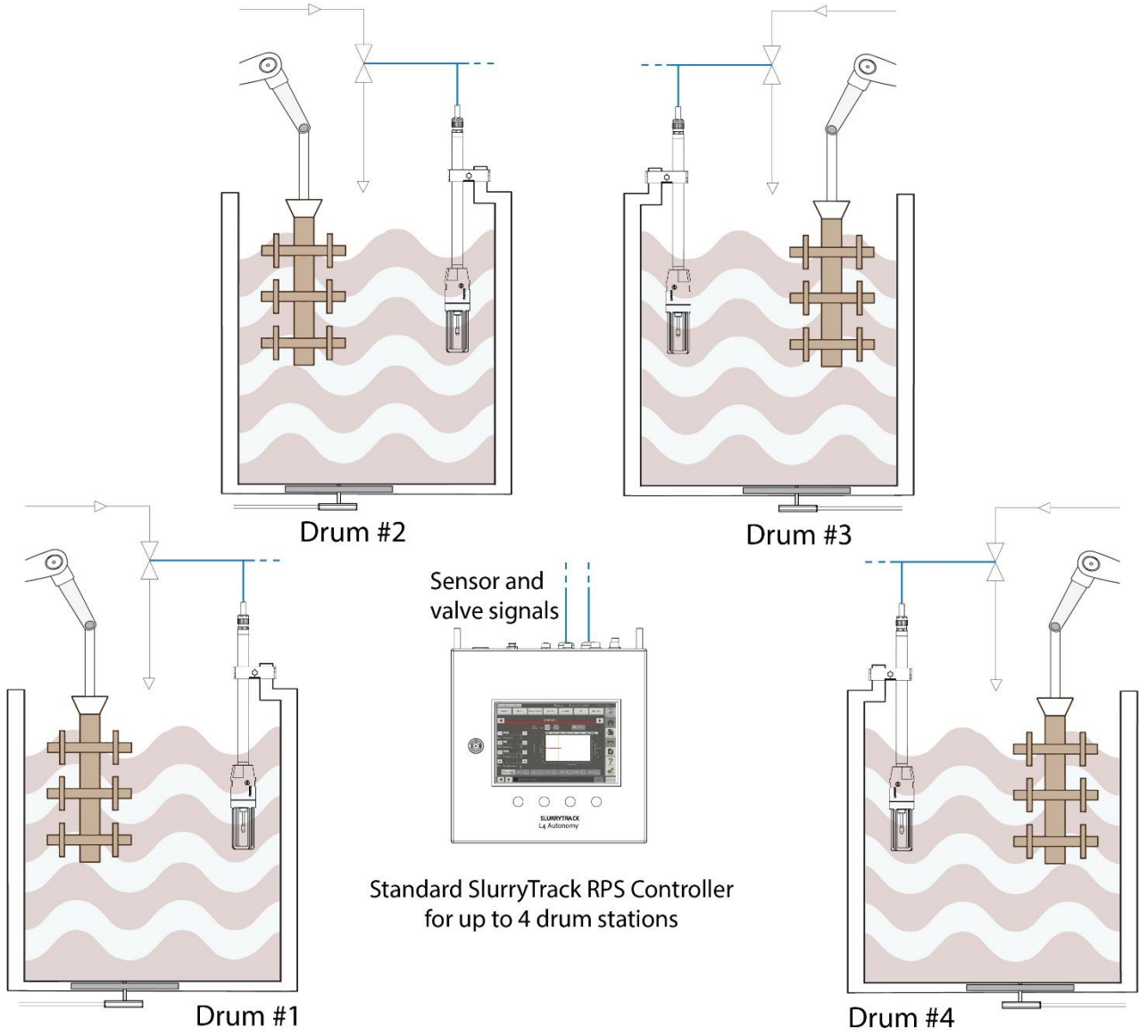
SlurryTrack for monitoring, data acquisition and control

STEP 1: Install SRV/SRD probe in slurry tank using tank mount adapter

STEP 2: Connect the probe to the SlurryTrack system. Power and operate.

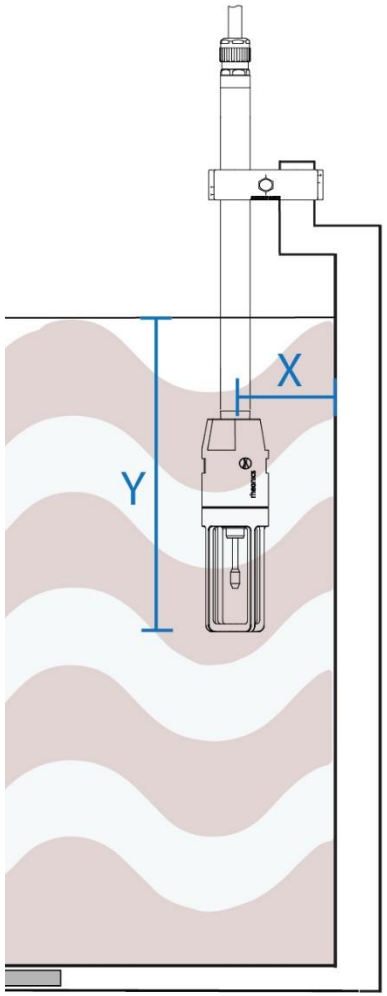
Monitor and control: For standard SlurryTrack RPS Systems, up to 4 sensors can be connected. If more are required, the RPS system can be customized.

Control only: For standard SlurryTrack RPS Systems, up to 6 sensors can be connected. If more are required, the RPS system can be customized.



SlurryTrack sensor installation recommendation

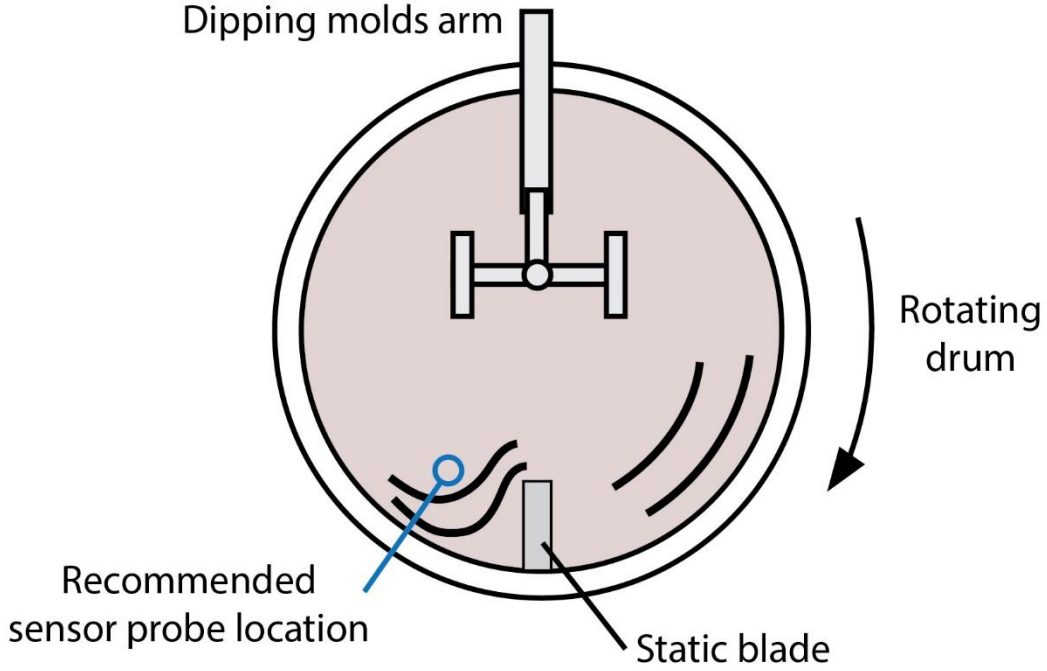
Sensor probe's insertion and distance from drum's wall



X: Distance from wall
5-8 cm [2-3″]

Y: Immersion below minimum slurry level
25-50 cm [10-20″]

Sensor probe location after static blade

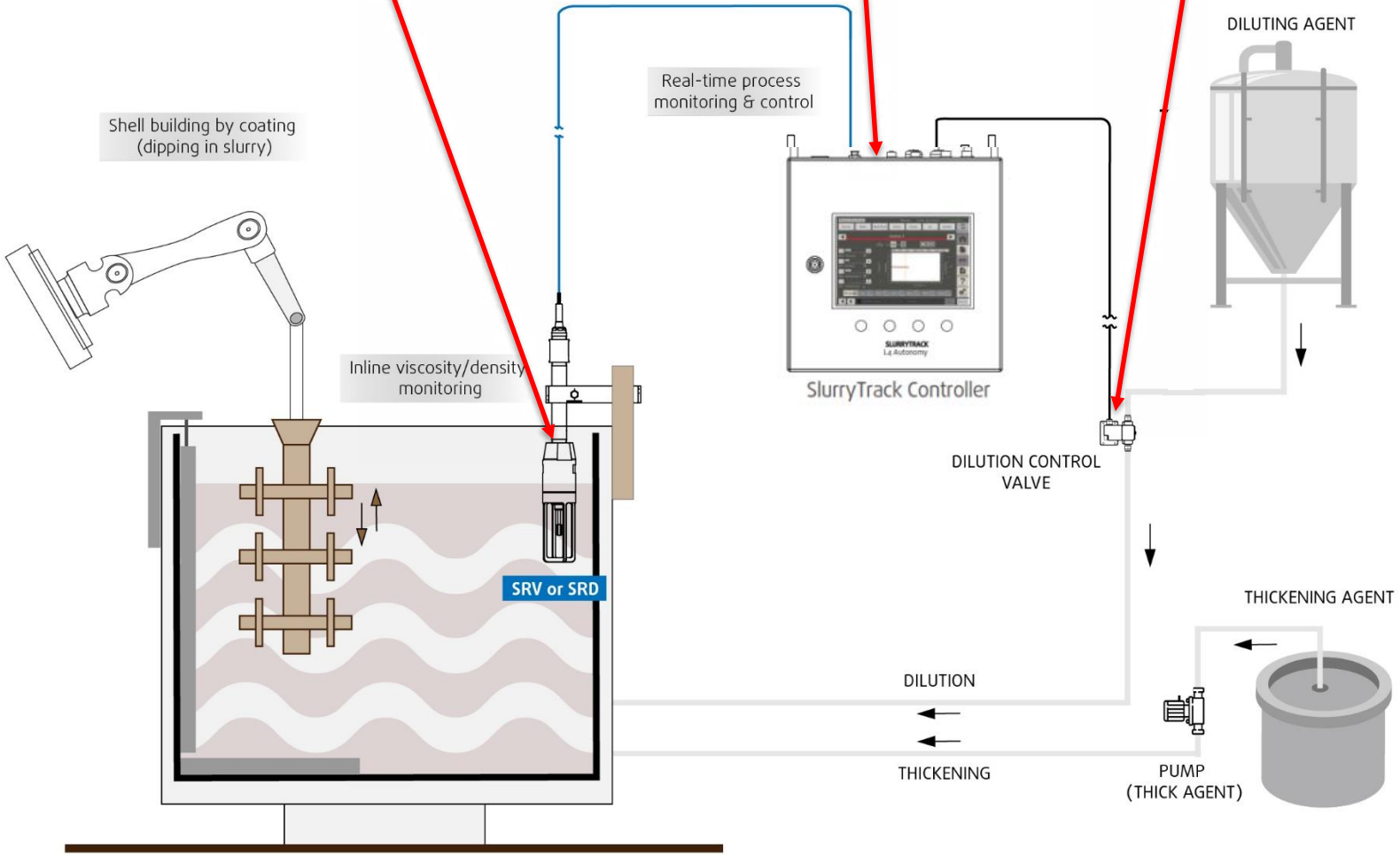


How does the RPS STK work?

1 Rheonics **SRV/SRD Sensor** is located directly in the slurry tank, monitoring and transmitting slurry viscosity to main control cabinet in real-time.

2 Rheonics Predictive Tracking **Controller** ensures precise control of slurry viscosity/density. Operator HMI gives one touch viscosity lock functionality.

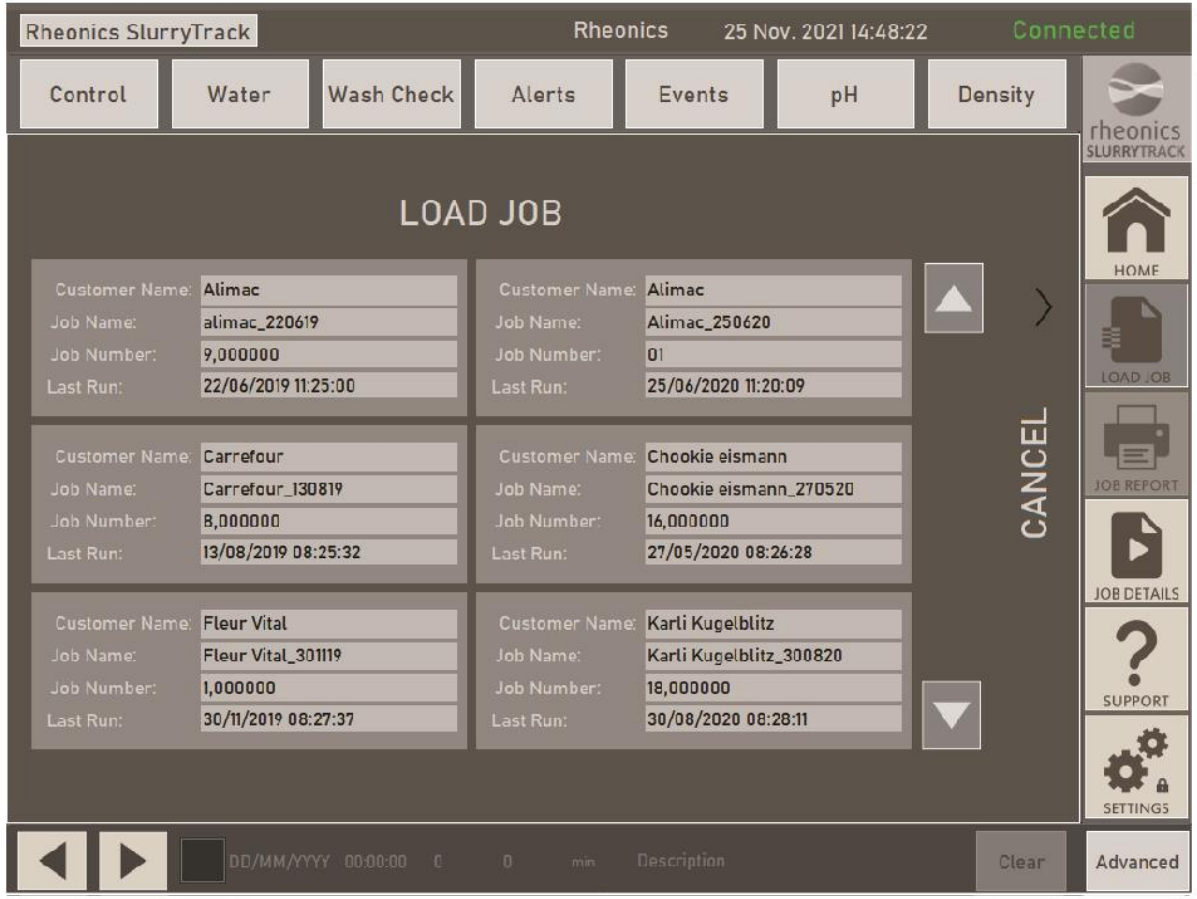
3 **Dilution control valve** connected to main control cabinet with feed line of diluent from central tank to each slurry tank.



Control system components

1. Rheonics SRV/SRD viscometers/density meters
2. Rheonics Predictive Tracking Controller
3. Dilution Control Valve

What to expect from monitoring software



Enter slurry type for each station

Start monitoring
Press “Lock” to start control

SlurryTrack PTC: Unlocking full automation in the shell room

Realizing the value of true automation inside the shell room.

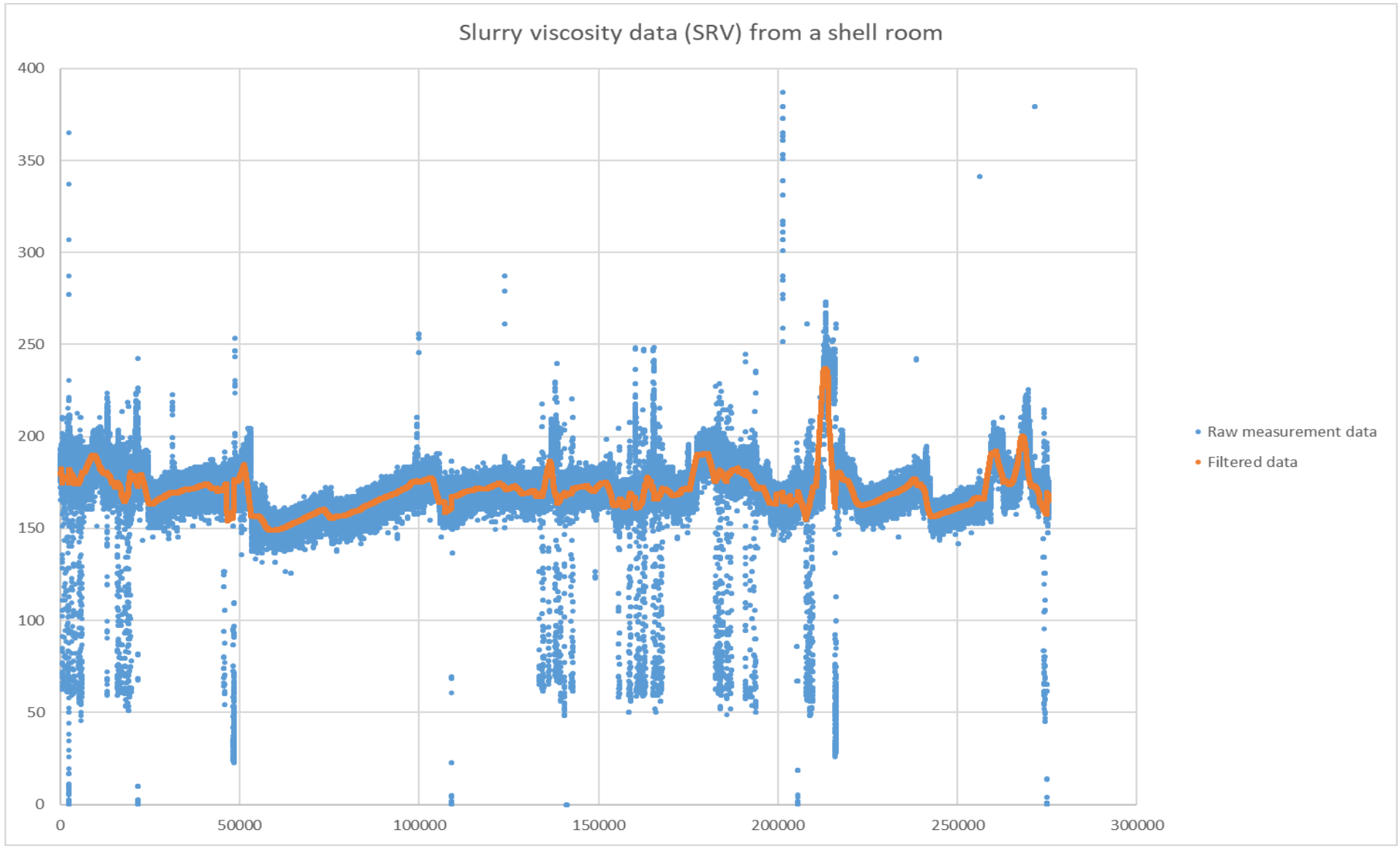
The SlurryTrack system is installed in a heavy stainless steel housing, which is equipped with its own **industrial PC and touch screen displays**. The operator can **choose a viscosity set point** from the touch screen interface, and **lock the system** to that set point.

- ***The ProcessLock Software comes with operator focused interface:***
  User interface of the **ProcessLock** enables one-click setting of slurry viscosity.

- ***Foundry 4.0 ready - enables full automation of shell rooms:***
  ProcessLock software measures, tracks and logs every variable. Data is available to the PLC and factory data acquisition systems. Plant managers, quality personnel and production supervisors get powerful interface to directly view process data, or to review it through process logs.

Rheonics Predictive Tracking **Controller** in a stainless steel housing

Typical SRV data trend from a shell room – 7 days data (Data filtering)



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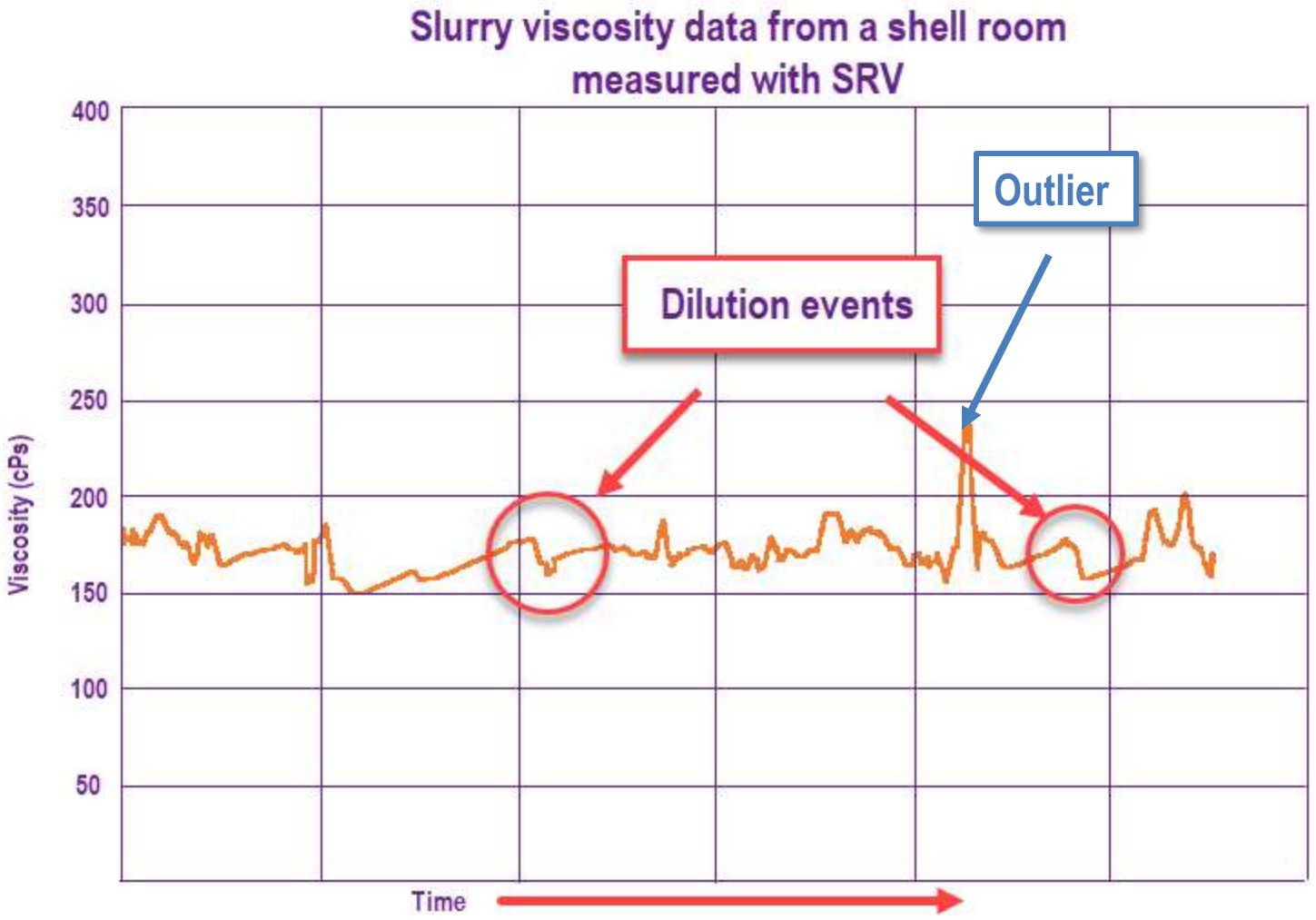

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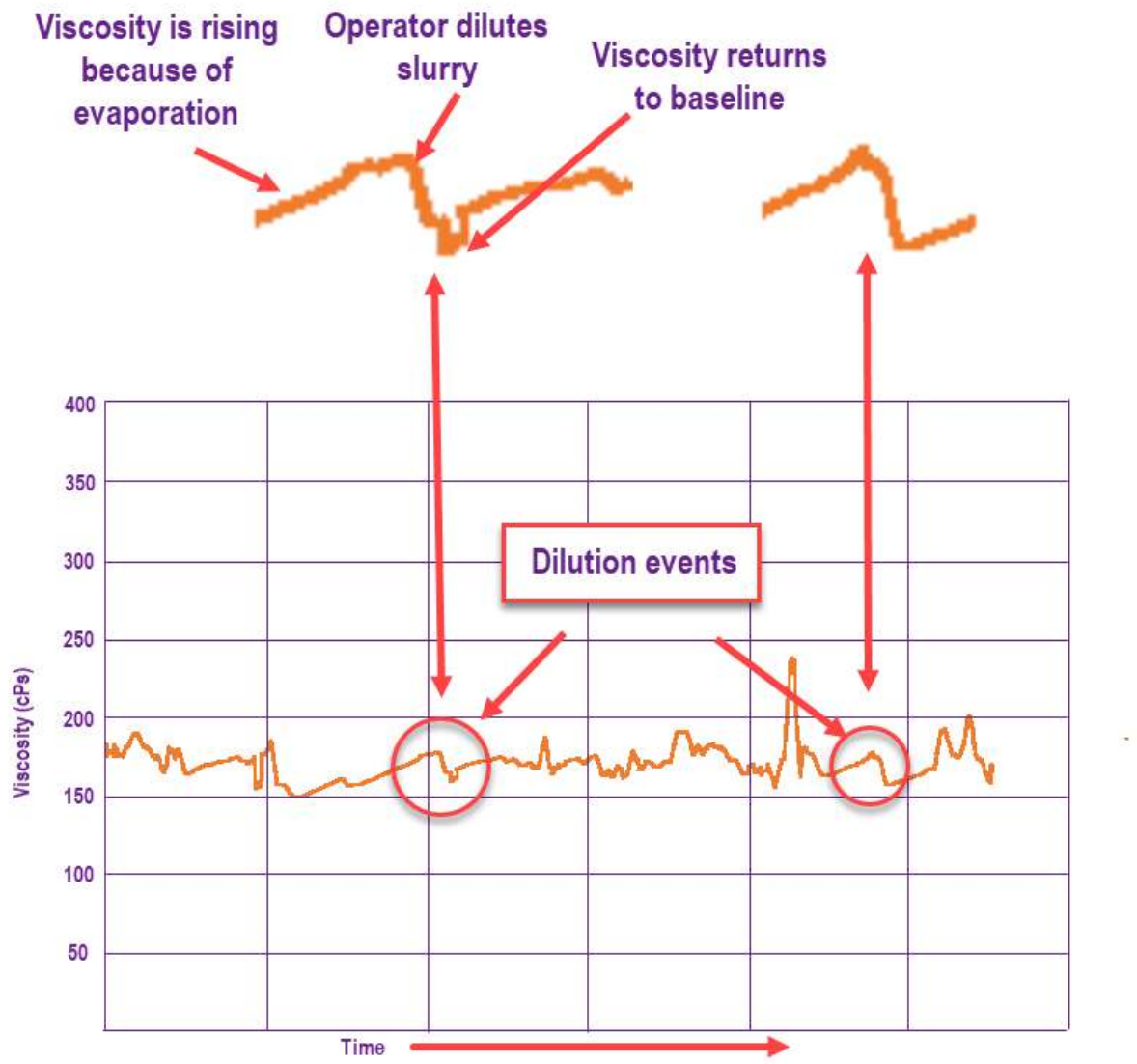
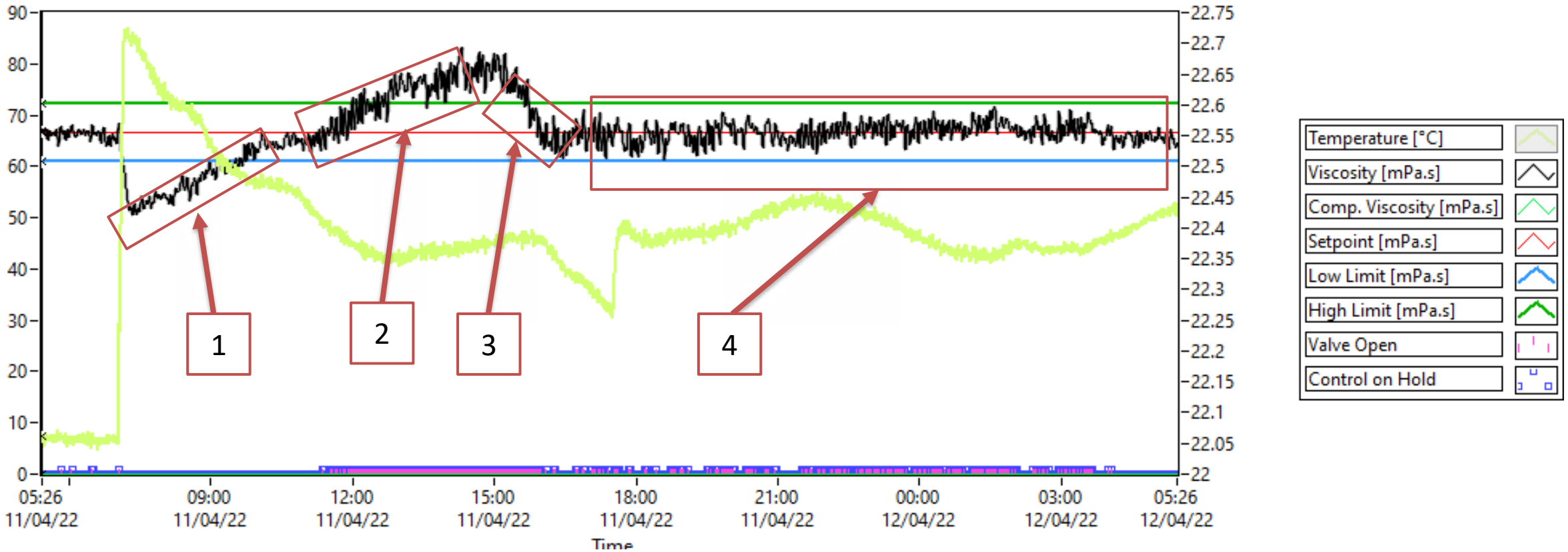


Highlighting important events on data trends from a shell room

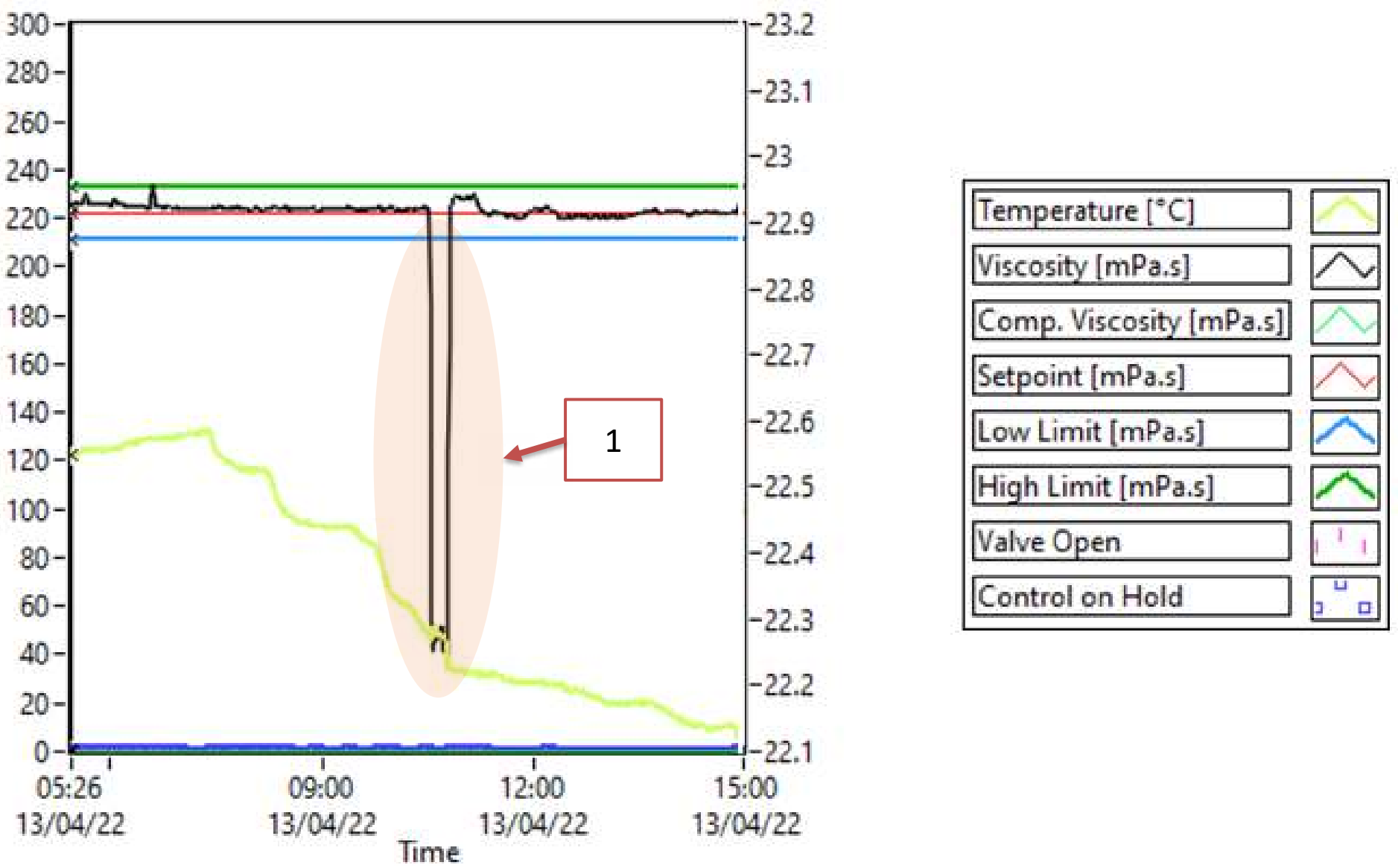


(1) Addition of new slurry - both viscosity and temperature change and detect this event;

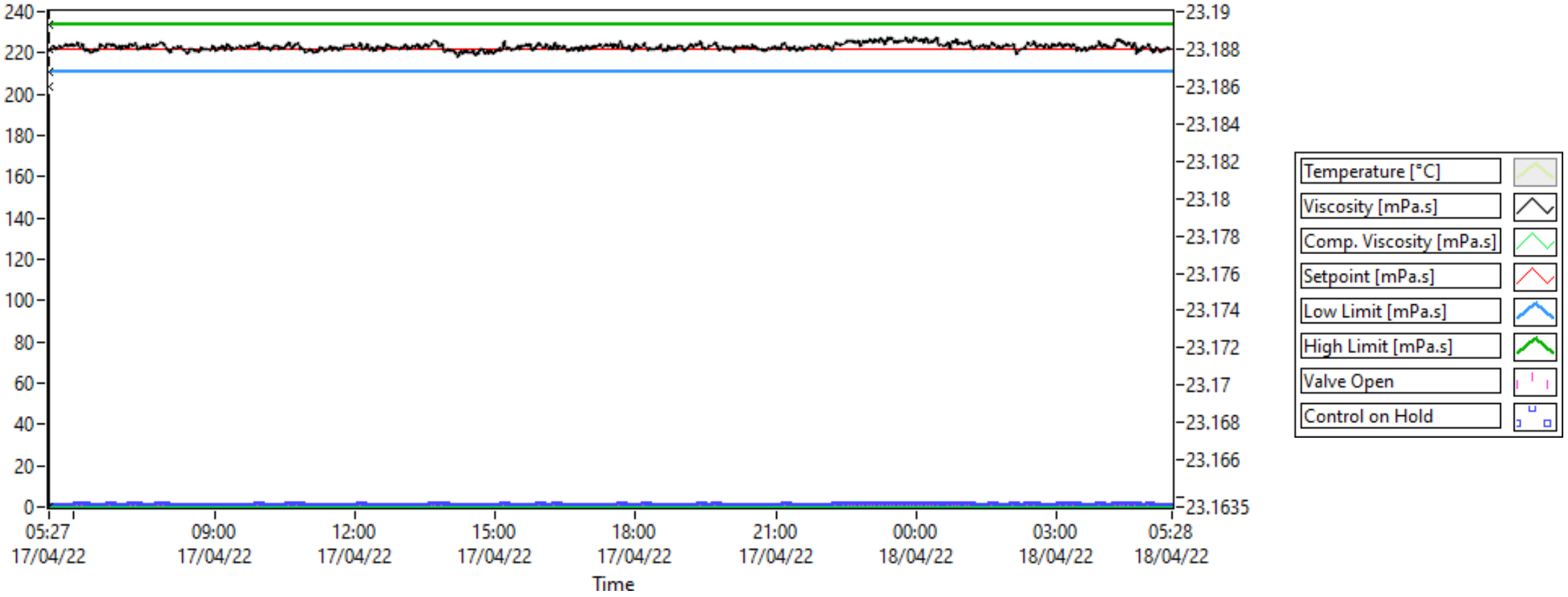
(2) Gradual change in viscosity of slurry due to evaporation;

(3) Dosing of the system automatically once the slurry viscosity is higher than upper bound;

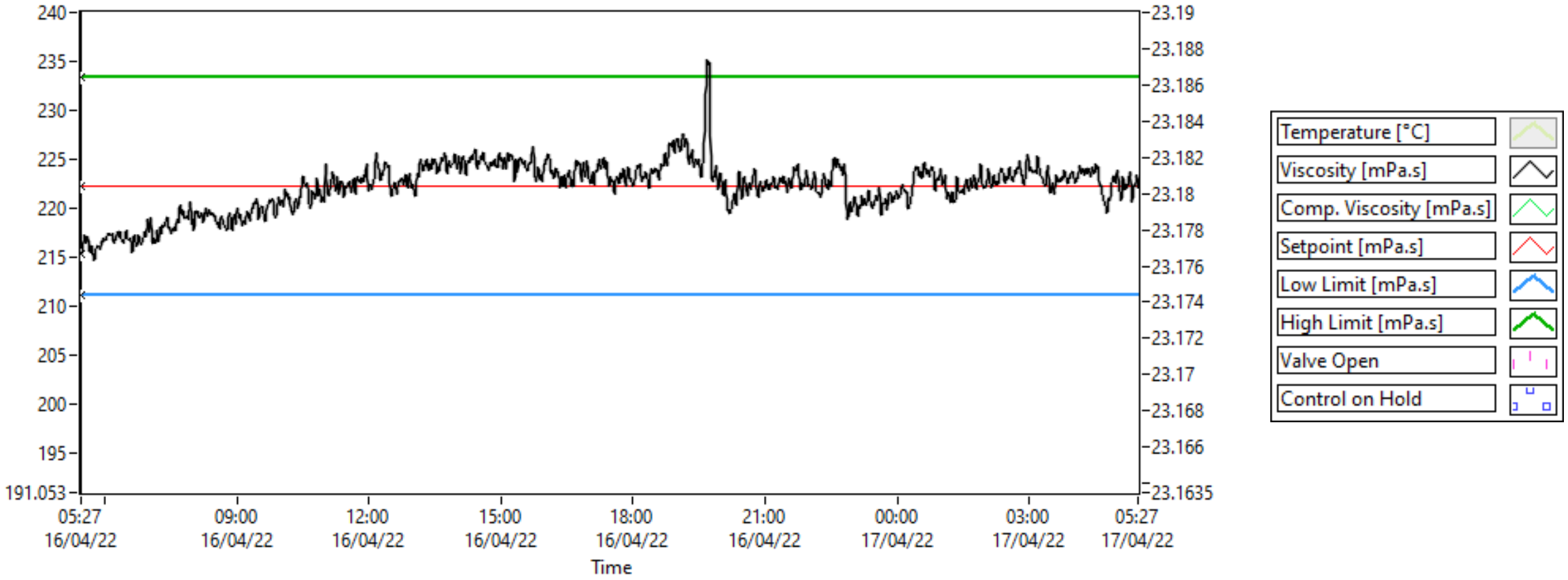
(4) SlurryTrack brings the viscosity to the setpoint and maintains it there



Stopping the tank creates a drop in viscosity and when it starts spinning again, viscosity comes back almost instantaneously to the original values.



SlurryTrack system ensures stable slurry viscosity through dosing over a long period



Shows a zoom in of the viscosity where it is below setpoint and is brought to the setpoint through predictive dosing and not reactive dosing control. The viscosity value never exceeds higher limits.

Sensor Operation – Fouling detection and SOP

- Ceramic coatings can be extremely difficult remove when hardened, so it is important that slurry is not permitted to harden or dry on the sensors. Since this may happen when a tank is being drained and switched, the sensor mount should be moved a water tank to avoid hardening. Operators have found that even hardened deposits can be dissolved in caustic solutions. Both SRV and SRD are made of 316L stainless steel which has excellent resistance to most common caustic solutions. SRD density sensors do not have the ability to warn about deposits, so they must be cleaned periodically.

- Even though SRV sensors warn of deposits, it is often a standard operating procedure for operators to clean the sensors periodically. Customers report cleaning cycles from as short as one or two days up to a few months. Operators are quick to understand the data from sensor and quickly adopt the in-built intelligence to make it part of their regular operation.

- After every cleaning, there is an option for operators to check and verify if the sensor is in calibration. The sensor is put in a fluid of known density and viscosity, and the sensor reading is verified. The four simple steps: Remove, Clean, Verify, Reuse can be part of the standard operating procedures in foundries which deploy the SRV or the SRD in their slurry tanks.

Shell rooms of the future – Rheonics facilitating automation goals

Goals of viscosity/density automation	How does SlurryTrack, ProcessLock and SRV contribute?
Knowledge transfer from experienced operators to an automated system	• Existing procedures can be programmed into SlurryTrack controller • Specific protocols can be memorized and recalled for repeat jobs
Viscosity and density automation bring slurry control up to Industry 4.0 standards	• Accurate, transparent viscosity and density control removes last barrier to full automation
Easy integration into existing shell room systems	• SlurryTrack supports seamless integration into existing processes and factory data systems • Monitoring, logging and self-check functions contribute to operator independence • Integration into factory data systems provides a path to data-driven process optimization

SlurryTrack – Customer experience and technology outcomes

User Benefits reported by our customers	• **Superior shell quality**, due to uniform coating • Efficient operations – **reduction in man hours** by 40% • Improved productivity – faster, automated system = **more molds** • Higher **Profitability** • **Reduced costs** • Easy **scalability** of operations
Technology Outcomes for Investment Casting Industry	• Reduced scrap, rejects, diluent consumption • Reduction in setup times and significantly easier cleaning procedures • Safer and cleaner workplace • Complete tracking and traceability of every job • Industry 4.0 connectivity enabling data-driven decision making and fault analysis

Conclusions

- Rheonics SRV and SRD with SlurryTrack bring accurate, repeatable slurry viscosity and density control up to the standards required of *modern industrial automation*.
- It removes the subjectivity and long time delays of traditional methods, making possible inline, real-time monitoring and control of slurry viscosity and density.
- SlurryTrack improves both shell quality and job-to-job consistency, reducing waste and rejects, while streamlining the viscosity and densitymeasurement and control process.

In doing so, it frees the operators to concentrate on what they do best: applying their art and experience to producing the best possible castings in an increasingly automated world of industry

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