Implementation of an Automated System for Slurry Viscosity and Density Measurement: Impact on Shell Quality and Labor Efficiency

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Summary

High-quality efficient investment casting relies on manual slurry consistency measurement to produce accurate and robust shells. Automation of slurry monitoring and control frees skilled shell room operators to apply their expertise and knowledge toward maintaining highest shell quality. We discuss an integrated measurement, data management system that enables maintenance of slurry consistency with minimal need for intervention from operators. In addition to automating tedious, often inexact manual measurements, stable and reliable slurry sensors pave the way for full automation of slurry consistency control and management.

Background

Rheonics, Nalco/Ecolab, and Texas Precision Metalcrafts (TPM) have cooperated on the deployment and evaluation of a system for measuring, monitoring and managing data on slurry density and viscosity in a full production investment casting facility.

Rheonics, a maker of precision inline density and viscosity sensors, teamed up with Ecolab, who integrated the Rheonics SlurrySense system with the 3D TRASAR real-time data management system, providing a turnkey slurry management system to TPM, that they installed in their shell room. This is the background against which the following system description, operating principles, and illustrative data were developed.

System Components

Rheonics SlurrySense inline density/viscosity monitoring system is the first link in the slurry monitoring chain. In contrast to the conventional manual measurement of slurry consistency using efflux cups and slurry weight cylinders, SlurrySense uses the Rheonics SRD sensor to provide continuous density and viscosity values at rates up to 20 values per minute. Since sensors are easily fouled by the very adherent investment slurry, SlurrySense incorporates CleanWave continuous self-cleaning capabilities to ensure low-drift, highly reliable measurement values.

Ecolab's 3D TRASAR technology provides a comprehensive data collection, cloud storage and management facility, complete with remote monitoring and control, to ensure continuous secure capture of slurry condition, including alarms for out-of-range deviations of slurry behavior and shell room operation.

Rheonics SRD Density/ Viscosity Sensor Operation

The Rheonics SRD is a compact, hermetically sealed and robust probe that can be submerged in a slurry tank to provide real-time measurements of density, viscosity and temperature. In situ temperature measurement is essential for accurate and reproducible measurement of density and viscosity since both of these properties are highly dependent on the fluid's temperature.

The SRD's sensing element is a "rod-and-wing" construction that performs minute torsional vibrations around the rod's long axis, shown in **Figure 1**.

The "wing" that is at the end of the portion of the resonator immersed in the fluid, has a nearly trapezoidal cross section. It oscillates torsionally around its central axis at a frequency of roughly 7 kHz, with amplitudes in the range of several nanometers.

As shown in **Figure 1**, the wing both displaces and shears the slurry as it vibrates. The displacement occurs perpendicular to the wing's surface, increasing its inertia in proportion to the fluid's density. This has the effect of lowering the resonator's resonance frequency. Shearing of the fluid occurs along the entire surface of the wing. Shearing of a viscous fluid absorbs energy in proportion to the viscosity, causing damping of the sensor's resonance. The electronics unit that is attached to the SRD measures both the resonance frequency and the damping of its resonator, from which the slurry's density and viscosity is calculated. The electronics unit prepares this data in digital form and transmits it through a variety of interfaces to ensure compatibility with existing data management and control systems.

CleanWave Self-Cleaning Sensor Probe

A serious impediment to sensor-based density and viscosity measurement has been the adherent properties of slurries. Their primary function is to form shells around wax patterns; they gladly attach themselves to any other objects immersed in the slurry tank. These deposits interfere with the fluid-sensor interactions that enable the fluid properties measurements, severely distorting, or even disabling the measurement process.

Rheonics has developed the CleanWave self-cleaning version of the SRD to inhibit deposits before they form. A pneumatically actuated high-amplitude, low frequency vibrator shakes the entire probe assembly, producing very high local shear stresses in the fluid, that cause deposits to be "shaken" off the sensing element, much in the manner of a wet dog shaking water off its coat by means of low frequency, high amplitude oscillations, as in **Figure 2**.

Since the frequency of these cleaning vibrations is much lower than the resonator's resonance frequency, the cleaning vibrations do not interfere with the measurement vibrations, allowing the CleanWave to run coninuously without adding any noise to the sensing system.

The effectiveness of the CleanWave system can be seen in **Figure 3**, which shows the output of the sensor system as the cleaning vibration is turned on (shaded area) and off.

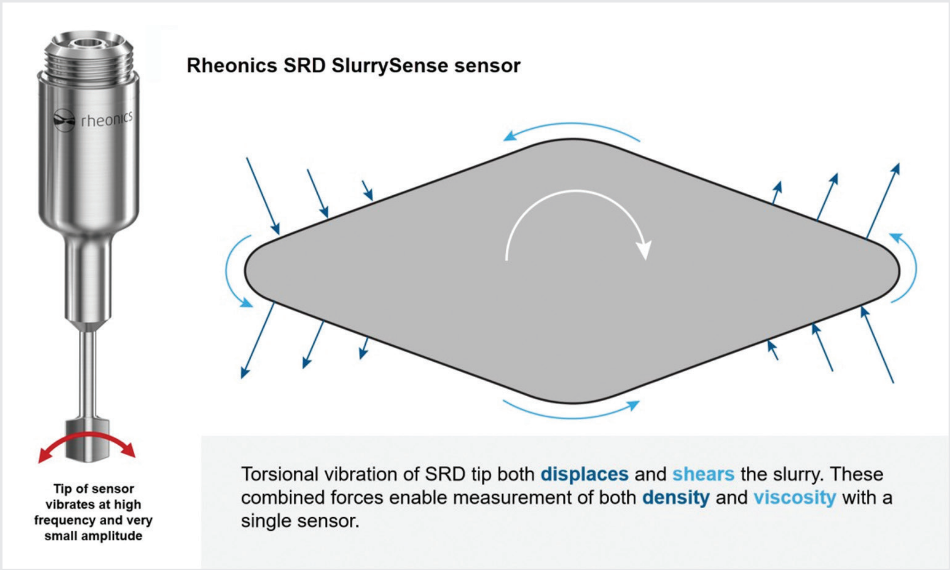

Figure 1: Rheonics SRD SlurrySense probe

Figure 2: (a) Rheonics SlurrySense SRD with CleanWave, (b) Wet dog shaking off water by low frequency oscillations

During the "on" periods, the sensor output always returns to the same constant value, relatively free of noise as compared with the measurements when it is turned off. As soon as the cleaning vibrations are turned off, the indicated viscosity and density become somewhat chaotic, showing deposition-driven instability that can be reversed by re-starting CleanWave vibration.

Operation In A Shell Room Environment

A Rheonics SlurrySense SRD with

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CleanWave self-cleaning system was installed in a slurry tank in Texas Precision Metalcraft shell room. During a 15 week period, the SlurrySense continuous readings were compared with cup measurements in order to establish a correlation between the two methods. Since efflux cup measurements are given in "cup seconds" and SlurrySense output is in centipoise, this initial period served two functions – to monitor the correlation between the two methods, and to use this correlation to calculate a conversion factor between cup seconds and centipoise. **Figure 4**, a 2 ½ week segment from the initial comparison period, shows the clear correlation between variations in slurry viscosity as reported by the SlurrySense and by parallel measurements with the efflux cup.

After this initial period established the robust correlation between the two methods, a second 5 week period of parallel measurements, a segment of which is shown in **Figure 5**, revealed the superior fidelity of the SlurrySense measurements compared with the sparse data obtained by efflux cup.

This is especially striking during weekends, in which the viscosity steadily increased due primarily to evaporation from the tank. Since the reliability of the SlurrySense measurements had been demonstrated during the initial 5 week comparison period, it became clear that the resolution and accuracy of the SlurrySense far exceeded that of the efflux cups.

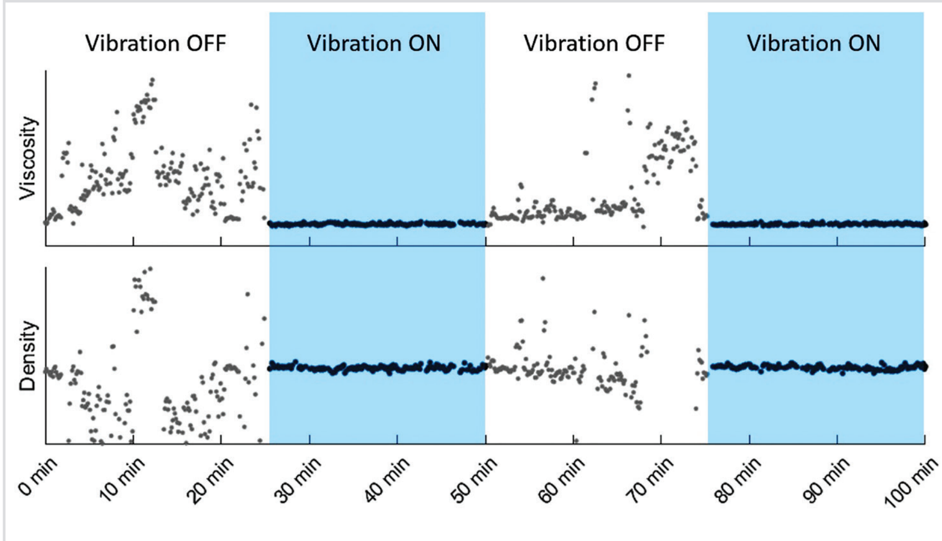

Figure 3: Stabilization of SRD readings by superimposed vibration

During a final 5 week period, a growing disparity between the SlurrySense and cup measurements was found, as shown in **Figure 6**.

Which of the two methods gave a more accurate picture of the slurry condition? The answer lies in comparison with historical data for the same tank.

Slurry tanks are to the shell builder what an instrument is to the musician. In order to produce fine, durable shells, the operator must "know their slurry" – to be able to judge its consistency not only from cup measurements, but primarily by its behavior.

The "behavior" of slurry is actually composed of two factors – how the slurry has behaved in the past, judged by the quality of shells the operator has produced, and how it is behaving – how does the current behavior compares with its past behavior. Is the slurry too thin, because it has been overdiluted? If too thick, is this because of evaporation, or is the binder beginning to gel?

Each of these behaviors requires a specific intervention by the operator. If an intervention is made on the basis of unreliable measurements, correcting it may result in anything from costly downtime, shell failure, or loss of the entire contents of the tank.

When we examine the final five weeks of measurements, the disparity

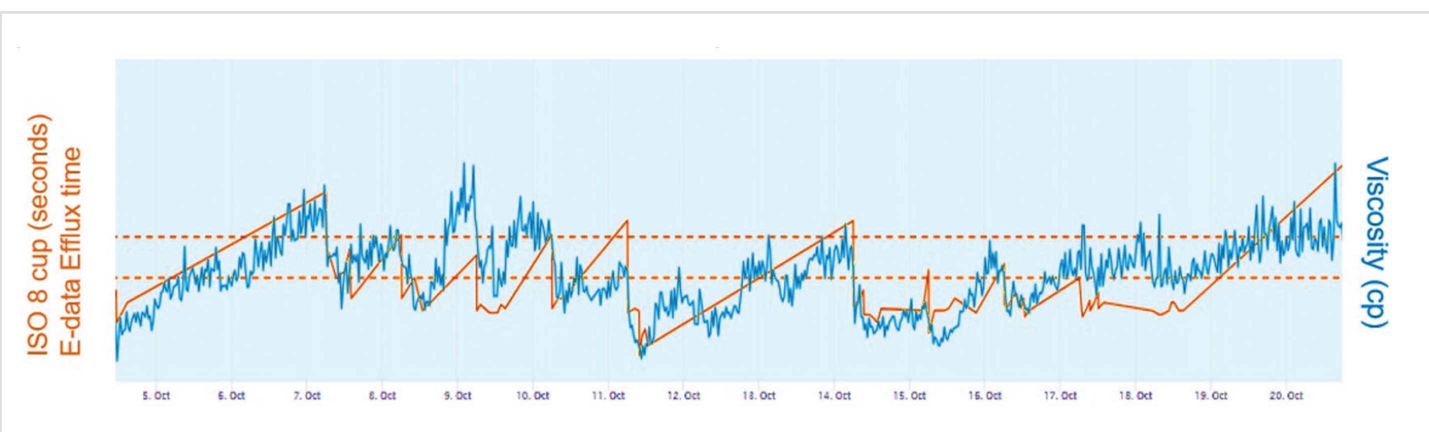

Figure 4: Correlation between SlurrySense and efflux cup data.

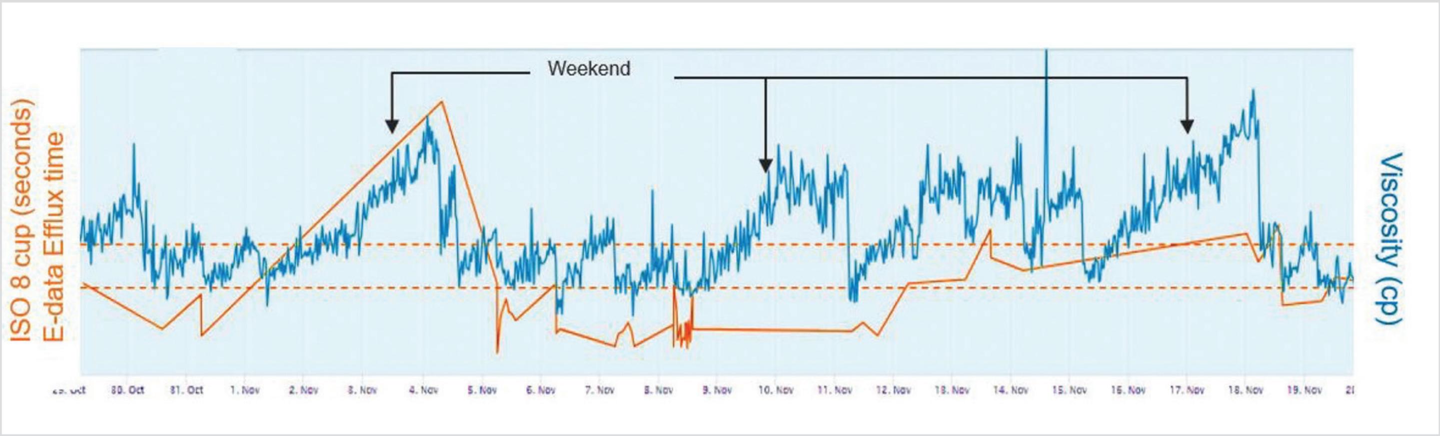

Figure 5: Segment of 5 week measurement period.

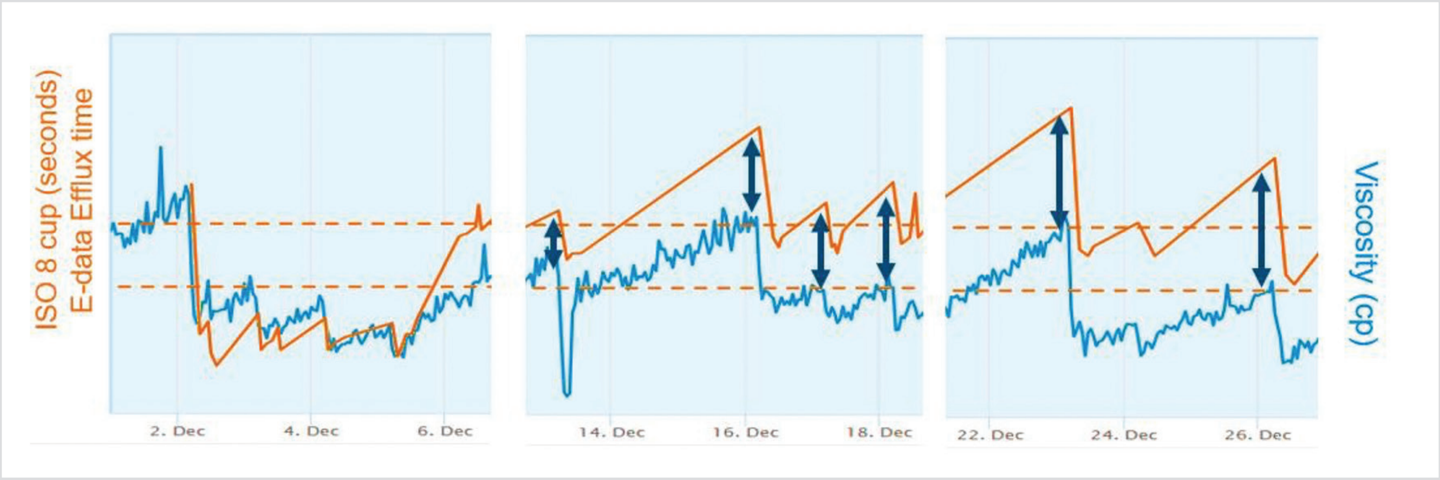

Figure 6: Segments from final 5 weeks, showing growing discrepancy between SlurrySense and efflux cup.

between the SlurrySense and efflux cup measurements is resolved by comparing both with the historical behavior of this tank. Analysis shows that the cup readings had diverged from the historical data for this tank, and therefore was no longer trustworthy. The solution was to replace the cup – the slurry needed no intervention!

TPM reported substantial economical benefits to use of the Rheonics/Ecolab SlurrySense – 3D TRASAR system, ranging from substantial reduction in viscosity measurement labor, improved data accuracy, reduction of slurry waste and overall positive return on investment in the system.

Future Outlook

Implementation of the SlurrySense/3D TRASAR system produced large, immediate benefits to TPM's slurry ecosystem. This pilot project points the way toward complete automation of slurry management, freeing operators to exercise full creative control over the shell building process while relieving them of the routine, less reliable management of slurry consistency.

Rheonics, Ecolab and TPM are working toward this goal by a program of continuous improvement, using feedback from active shell room operations to provide slurry data of sufficient quality to run a consistency control system without operator intervention. This process is supported by the "monitor and notify" feature of the 3D TRASAR data management system.

In order to fully automate slurry management, it is essential that the control system's judgements correspond to the judgement of an experienced operator. This means that noise and outliers present in the SlurrySense output should be reduced to the point where the operator's eye doesn't have to perform excessive "filtering" in order to understand the significance of any deviations from ideal consistency. And improving the data quality also makes the data more reliable for control purposes.

This process of continual improvement, with the ultimate goal of full automation of slurry monitoring and control is the immediate goal of our cooperation. Encouraged by TPM's positive experience with SlurrySense/3D TRASAR, we are actively working on advanced decision making systems that will ultimately support full slurry ecosystem automation.