Viscosity Monitoring Using a Solid State Sensor for Ceramic Slurry Applications

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Viscosity monitoring of ceramic slurries in the inve stment casting process is essential in maintaining process control and achieving final part quality specifications. While foundries use several methods to provide process control for their slurries, by far the most important tool available to the process engineer is a viscometer.

Measuring the viscosity of the slurry is a rapid method of determining the overall quality of the slurry; but conventional mechanical and electro-mechanical viscometers designed primarily for laboratory measurements are difficult to integrate into the control and monitoring environment. As a consequence, many companies rely on decisions based on intermittent "snapshot" data (data acquired from various operators over the course of the process cycle from various shifts) acquired from periodic sampling (using different selection of flow cups) where conventional instrumentation can be affected by temperature, shear rate and other variables.

Acoustic wave (AW) sensors offer a number of advantages over conventional mechanical and electromechanical viscometers as they are small solid-state devices that can be completely immersed in the slurry to provide an instantaneous viscosity data stream for embedded decision making. The sensors are unaffected by shock or vibration or by flow conditions so they can be used in harsh operating conditions with a temperature range of 0°C to 80°C with a high degree of accuracy. At the same time, sensor measurements are not affected by particulates in the slurry.

The viscosity sensor, which can compliement other material specific data obtained, can provide instantaneous online viscosity and temperature data and offers universal plug-and-play connectivity for integration to control platforms. The sensors have been tested in actual commercial slurry applications and are currently installed at customer sites in rigorous environments where ROI benefits have been realized.

Long-term benefits of accurately maintaining the slurry viscosity include consistent accuracy of readings throughout the process cycle, ability to control the slurry to specifications determined, and ability to correlate to measurements taken with other areas of the process.

The design and manufacture of acoustic wave (AW) based sensor products, requires the ability to integrate leading-edge principles with mature semiconductor manufacturing know-how. One vendor has developed a unique method to offer a viscosity sensor with a wide dynamic range (air to several thousand cP) in a single sensor (**Figure 1**).

A commercially available, robust, reliable and cost-effective surface acoustic wave solid-state viscometer for integration into in-line, real-time monitoring and process control systems for scalable applications is shown in **Figure 2**. The sensor output is in standard industry protocols and can easily be acquired by any control system.

The sensor has no moving parts (other than the atomic scale vibration of the surface) and– due to the high frequency of the vibration, several millions of vibrations per second– is independent of flow conditions of the liquid and immune to vibration effects of the environment. High temperature electronics allow a very wide operating temperature range for the sensor.

The importance of these acoustic sensors lies in their distinctly different measurement principle. Whereas one class

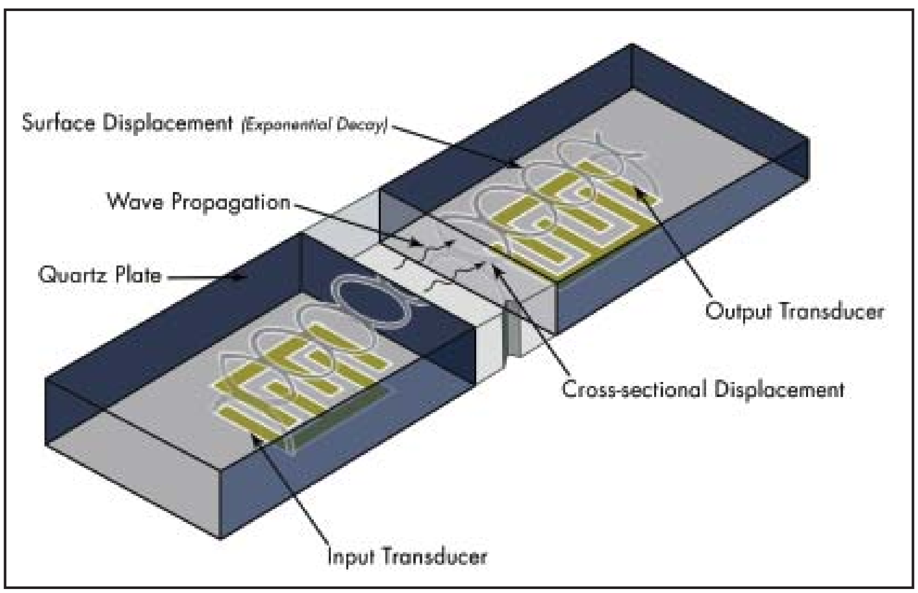

Figure 1. The solid-state sensor uses an acoustic waveguide with electrical transducers on one surface and being in contact with the fluid on the other surface.

Figure 2. Commercially available solid-state viscosity sensor.

of mechanical devices measures kinematic (flow) viscosity and the other class measures intrinsic (friction) viscosity, the acoustic wave (AW) sensors measure acoustic impedance.

The viscosity measurement is made by placing the quartz crystal wave resonator in contact with liquid. The liquid's viscosity determines the thickness of the fluid hydro-dynamically coupled to the surface of the sensor. The sensor surface is in uniform motion at a frequency known by design, and amplitude is determined by the power level of the electrical signal applied to the sensor. The shear wave penetrates into the adjacent fluid to a depth determined by the frequency, viscosity and density of the liquid **(Figure 3)**.

Acoustic viscosity is calculated using power loss from the quartz resonator into the fluid. The unit of measure is acoustic viscosity (AV) .

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The acoustic wave resonator supports a standing wave through its thickness. The wave pattern interacts with electrodes on the lower surface (hermetically sealed from the liquid) and interacts with the fluid on the upper surface. The bulk of the liquid is unaffected by the acoustic signal and a thin layer (on the order of microns or micro inches) is moved by the vibrating surface. Also present is a proprietary hard-coat surface that is scratch proof and abrasion resistant which allows the sensor to be operable in extreme environments and enables the acoustic wave sensor to be a suitable candidate for harsh slurry applications. Finally, a temperature chip inside the sensor measure temperature at the same time as viscosity measurements are taken.

Though solid-state sensors for slurry application are relatively new, significant testing as been accomplished by commercial customers.

One customer who currently uses a solid-state sensor completely immerses the sensor into their slurry to monitor the viscosity **(Figure 4)** and make sure it is within established control parameters.

The data was acquired at one minute intervals (which is user configurable) and acquired on an industrial control system for real-time viewing and analysis. The sensor was immersed continuously for more than two weeks to monitor temperature and viscosity.

The conclusions that can be drawn from this data and the customer testing are:

1. Solid-state sensors are reliable and robust enough to render accurate readings in the slurry for process control.

2. Given the on-line and real-time nature of the data acquired, with data acquired with great frequency, process engineers can make quick decisions and confirm the quality of the process.

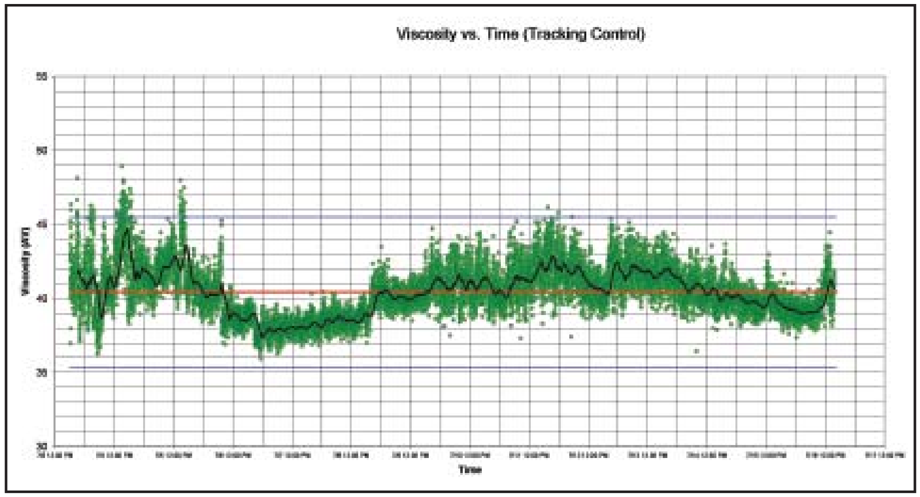

Figure 4. Viscosity vs Time data for approximately two week interval showing process control within established upper and lower (the blue lines) bounds. The temperature was approximately 76°F for the duration of the ru

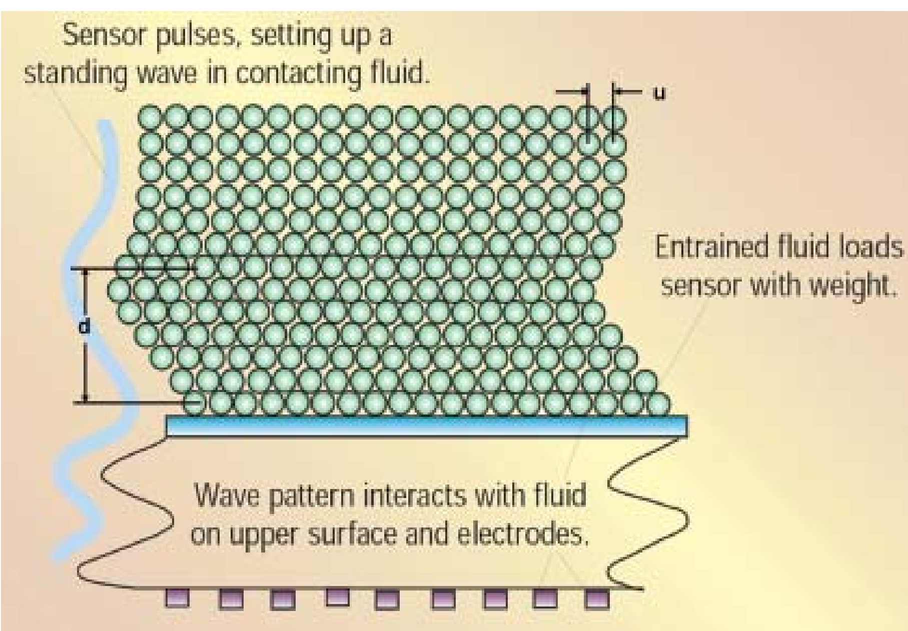

Figure 3. Cross section of the sensor showing transducers on the lower surface and liquid molecules on the upper surface.

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