White Paper | Process Characterization of Slurries and Dry Bulk Utilizing Non Nuclear Density Meter Technology

Introduction

The Red Meter is driven by a breakthrough technology and novel approach to safely measuring the process characteristics of any media flowing through a pipeline on a continuous basis in various environments.

The Red Meter may be best described as a *Process Characterization Device* (PCD) that is deployed in conjunction with process control methodologies, such as Statistical Process Control (SPC) to enable continuous, real-time, in-line measurement of critical media characteristics. The Red Meter produces a unique "Process Signature" or *Red Meter Signature* when deployed in any continuous liquid, slurry or dry bulk media pipeline or conduit. The advanced processor couples with the Machine Learning capabilities of the unit enable the instantaneous interpretation of the Red Meters Signature. This process information and interpretation can be presented instantaneously on a built in display, or delivered to a remote location using 4-20mA, Modbus or any other standard industry communication protocol. With advanced machine learning techniques, accurate interpretation of the Process Signature may provide additional useful information, such as "sticky" valves, slow actuators, leakage, blockages, media flocculation, process anomalies, gas entrapment etc. and may alert the operator to take corrective action to avoid process or production issues should any anomalies be detected.

The continuous signature produced by the Red Meter enables the instrument to be employed as a Statistical Process Control (SPC) device to monitor process variation. It may also be employed as a detector, monitor, process controller or process improvement device as follows:

- **As a detector**: - the Red Meter can alert the operator over any communications network to any situation that may cause the process to deviate beyond specified control limits, as defined by the end user.
- **As a monitor**: - the Red Meter may provide the operator with critical and continuous process variation data in real time, which may be displayed on the actual device or relayed to a control room. The operator may employ the Red Meter to assess process capability (Cp, Cpk) prior to commissioning the Red Meter as a process monitor.
- **As a process controller**: - the Red Meter may be employed as a feedback device as part of an automated closed loop process. When used in this scenario, the Red Meter may alert other computer-controlled devices to take corrective action automatically and instantaneously should a process related issue or change be detected or required.
- **As a process improvement device**: - the Red Meter leverages the science of machine learning to improve its accuracy and proactively identify process drift, based in its historic measurements. Future integration of Artificial Intelligence means that the device may be equipped to communicate with similar devices at different areas of the same process, or with other processes within the operation – even if they are thousands of miles away.

Principle of Operation

The heart of the Red Meter consists of a flexible conduit or Cartridge that enables the instrument to measure mass when subjected to various forms of micro-deformations. These deformations may be caused by internal pressure changes, changes in mass of the media, a change in temperature of the system or components of the system, vibration etc., which may be induced by specific flow characteristics, process variations from outside influences or some combination of these variables. Conversely, due to its anisotropic nature, the composition of the cartridge may also be varied to yield a specific micro-deformation response to known process variables in order to improve the signal to noise ratio of the instrument.

The principle of operation of the Red Meter relies on understanding, accurately measuring and through complex algorithms, compensating for the following:

1. Addition of internal mass
2. Changes in media temperature
3. Changes in internal pressure
4. Changes in geometry due to wear
5. The velocity and characteristics of the flow
6. The stability of a fixed datum
7. The effect of external elements, such as temperature, wind load, vibration or other forces that may cause movement in the structure of the device
8. The rate at which critical data may be acquired, processed and reported
9. The extent to which current and historic data may be employed to improve the accuracy and precision of the device
10. The natural and unnatural degree of erosion, corrosion or other deterioration mechanisms

In house, field testing and mathematical analysis have allowed Red Meters' engineers and scientists to identify and isolate the effect of these variables on the desired outputs. When properly equipped, outputs include Flow, Pressure, SG, Density, Total Slurry Flow, Total Slurry Mass Flow, Solids Flow, Solids Mass Flow, Percent Solids, Temperature, Accumulator or some combination or derivative of these characteristics.

The Red Meter employs state of the art electronics with high accuracy and precision measuring devices. Coupled with high speed data processing, inputs from the individual sensors can be almost instantaneously assessed through a series of proprietary algorithms, yielding a real time characterization of the media flowing within any pipeline. When the known effects of the variables are accounted for, the exact mass flowing through the flexible cartridge due to its fixed volume, may be ascertained.

The data from the Red Meter is presented as a continuous stream or “Process Signature”. Given the nature of the variables measured, coupled with a thorough understanding of the effect of these variables on the movement of the cartridge, specific characteristics of the Process Signature may be identified as indicators of specific media flow characteristics, such as flocculation, media surges, gas entrapment, malfunctioning process equipment, process kicks etc.

Figure 1 shows the elements required in order to make the Red Meter function within acceptable limits of accuracy, precision, repeatability and reproducibility.

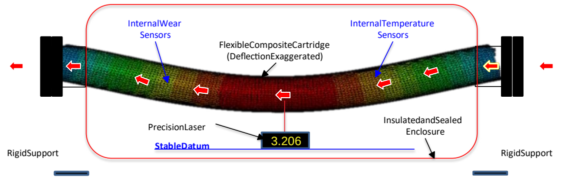


Figure 1: *Basic Operating Concept – Critical Components*

Compensation Algorithms

In order to achieve the required level of performance, a complex composite structure was developed for the flexible member. By nature, the component is anisotropic in nature, consisting of linear, elastic, viscoelastic and hyperelastic elements. As a result, very complex compensation algorithms are required to ensure effective operation of the instrument.

Compensation algorithms are used today in many applications, from determining consumer buying habits to stabilizing drones. Generally, the algorithms consist of a series of linear and non-linear equations that are based on physics, statistics or both. As a result of the compact nature of modern computing power coupled with remote connectivity, it is possible to deploy very sophisticated algorithms that were previously unavailable or impractical.

The algorithms employed by the device are based on the physical governing equations (physics). Due to the complexity of the material system, advanced predictive engineering techniques, including Finite Element Analysis (FEA) and Computational Fluid Dynamic (CFD) techniques were employed to develop and validate the algorithms. Additionally, these techniques were augmented by data science and machine learning technology (statistical methods) in order to achieve the desired degree of accuracy.

Figures 2 and 3 show the basic physical governing equations for calculating the tangential and radial stresses in a cylindrical conduit and the maximum deflection in a simple beam. Similar basic governing equations were used as a starting point for all other compensated parameters.

$$\sigma_t = \frac{p_i r_i^2 - p_o r_o^2 - r_i^2 r_o^2 (p_o - p_i)/r^2}{r_o^2 - r_i^2}$$

$$\sigma_r = \frac{p_i r_i^2 - p_o r_o^2 + r_i^2 r_o^2 (p_o - p_i)/r^2}{r_o^2 - r_i^2}$$

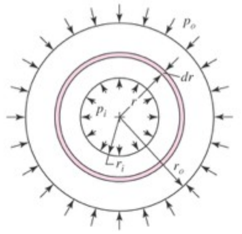
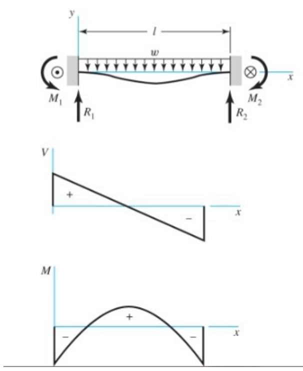


Figure 2: *Relationship of Pressure and Stress*

16 Fixed supports—uniform load



$$R_1 = R_2 = \frac{wl}{2} \qquad M_1 = M_2 = \frac{wl^2}{12}$$

$$V = \frac{w}{2}(l - 2x)$$

$$M = \frac{w}{12}(6lx - 6x^2 - l^2)$$

$$y = -\frac{wx^2}{24EI}(l - x)^2$$

$$y_{\max} = -\frac{wl^4}{384EI}$$

Figure 3: *Relationship of Load and Beam Deflection*

Effectiveness in Various Media Types

Since the Red Meter’s performance is predominantly based on the movement of a repeatable material under load, by definition it can register the mass of any media that passes through it. In addition, since the movement of the repeatable material may generate a unique distortion “fingerprint” or “signature” for various processes and features, the instrument can be used to measure liquids, slurries or bulk solid materials. Should the media contain entrapped gas, or should the process flow be interrupted and begin to drain, the Red Meter will continue to register the mass of the material remaining within the cartridge. Static process data may provide useful information to the process engineer, however the unit’s ability to continuously monitor a dynamic process with a less than full pipe, or one containing solid media has proven most valuable in end use applications.

Red Meter and Nuclear Density Meter

Figure 4 shows the results for the Red Meter (Red) and a Nuclear Density Gauge (Blue). A period of approximately 30 days of a mining production process was monitored a typical mining slurry using both instruments. The operational segments analyzed represented two different sets of process conditions in order to assess the ability of each instrument to adapt to changing process variations.

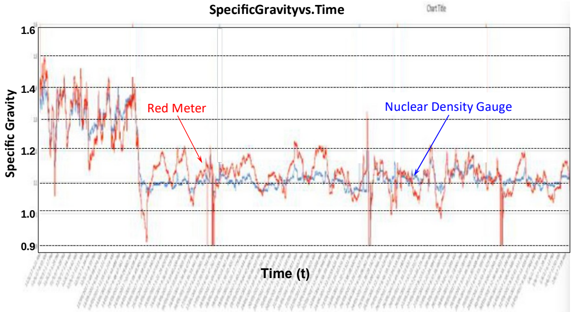
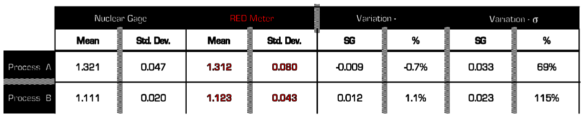


Figure 4: *Red Meter vs. Nuclear Density Meter*

A statistical analysis was conducted in order to determine the level of correlation between the Red Meter and the Nuclear Density Meter. Table 1 shows a more detailed comparison of the mean and standard deviation of both data populations. The variance between instruments is highlighted for clarity.



	Nuclear Gage		RED Meter		Variation -		Variation - σ	
	Mean	Std. Dev.	Mean	Std. Dev.	SG	%	SG	%
Process A	1.321	0.047	1.312	0.080	-0.009	-0.7%	0.033	69%
Process B	1.111	0.020	1.123	0.043	0.012	1.1%	0.023	115%

Table 1: *Red Meter vs. Nuclear Density Gauge*

The Red Meter operates on an entirely different physical principle than that of the nuclear density gauge. The Red Meter also takes advantage of advanced technologies such as Machine Learning to "learn" to actively identify process issues and flag potential and problematic process variations to avert process interruptions or safety issues.

From the extensive number of data points shown in Figure 4, it appears that the trend and average of both meters appear to track and compare favorably to each other. One can clearly observe the process change in Figure 4 as the Specific Gravity of the media transitioned from 1.32 in Process A to approximately 1.11 SG in Process B.

The process Standard Deviation measured by the Red Meter was as much as 115% greater than that of the Nuclear Density Meter. It can be clearly seen from the figure that while both meters appear to be reading similar trends and averages, the Red Meter does in fact appear to be more "sensitive", revealing more detail about the process in question and providing a clearer indication of the true Cp and Cpk.

Red Meter vs. Coriolis Meter

Coriolis meters are very accurate and reliable, however they tend to be costly in diameters larger than 2". The devices may also suffer issues resulting from erosion in abrasive media due to their non-linear geometries and flow path. As a result of their geometries, Coriolis Meters tend to be more prone to blockage by media that contain high concentration of solids, particularly if the device is fitted to a smaller diameter slipstream conduit. Chemical attack can also be an issue for the Coriolis Meter, since it may not be possible to match the corrosion resistance of the lining used in the actual pipeline itself.

As a result of the cost, when used in suitable media, Coriolis meters are often fitted to a slipstream line branching from the main line. By default, this provides a "sample" of the media, and since all of the media cannot be accounted for in a single measurement, it may be classified as a discrete sampling method. In an environment of Statistical Process Control, continuous and real time sampling is essential to enable optimum process control. Additionally, damping of the data in many situations, partially filled pipes, entrained gas etc. may all contribute to inaccuracies or a delay of the data reported by some instruments.

Figure 4 shows a typical comparison of a Red Meter while run in parallel with a Coriolis Meter.

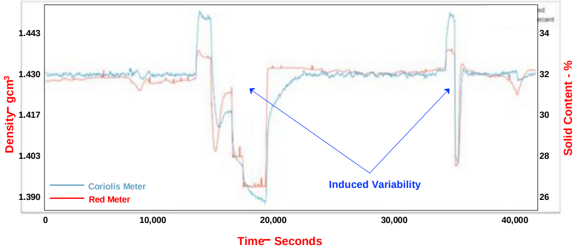
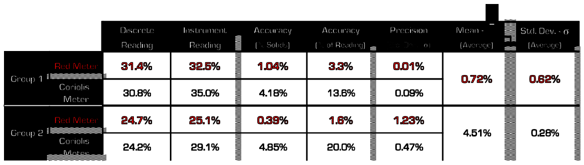


Figure 5: *Red Meter vs. Coriolis Meter*

Table 2 compares the results of a typical discrete sample analysis in an actual manufacturing process, with samples being compared from both a Red Meter and a Coriolis Meter.



		Discrete Reading	Instrument Reading	Accuracy (% Solids)	Accuracy (% of Reading)	Precision (Std. Dev. - σ)	Mean - (Average)	Std. Dev. - σ (Average)
Group 1	Red Meter	31.4%	32.5%	1.04%	3.3%	0.01%	0.72%	0.62%
	Coriolis Meter	30.8%	35.0%	4.18%	13.6%	0.09%		
Group 2	Red Meter	24.7%	25.1%	0.39%	1.6%	1.23%	4.51%	0.28%
	Coriolis Meter	24.2%	29.1%	4.85%	20.0%	0.47%		

Table 2: *Red Meter vs. Coriolis Meter Results*

In terms of predicting the actual percent solids, the Red Meter was closer to the actual value in both sample groups tested. The discrete samples yielded percent solid values of 31.4% and 24.7% on the Red Meter line for groups #1 and #2 respectively, versus values of 30.8% and 24.2% on the Coriolis slip stream line. In summary, the Red Meter averaged within 0.72% of the actual solid content vs. 4.51% for the Coriolis Meter, again with an overall larger standard deviation. This may most likely be attributed to the absence of damping in the Red Meter in order to maximize the sensitivity of the unit in the specific application.

Dry Bulk Applications – Blend Identification

The technical challenge associated with measuring the mass of dry bulk media on a continuous basis is not trivial. The principle employed by the Red Meter however is very simple and robust. As media flows through the Red Meter the unit determines its mass due to gravity.

In the dry bulk scenario assessed, the process was run at steady state as a dense phase media. The density of the media passing through the Red Meter was accurately measured with a pycnometer and calculated for comparison purposes. As the material flows in a continuous process at steady state, the bulk density of the entire process media may be determined in real time with a significant degree of accuracy. In the example shown in Figure 6, three different blends of dry bulk cement and hollow glass microspheres are superimposed on a plot od bulk density as reported by the Red Meter. It can be seen that the blends may be readily identified by their measured bulk densities.

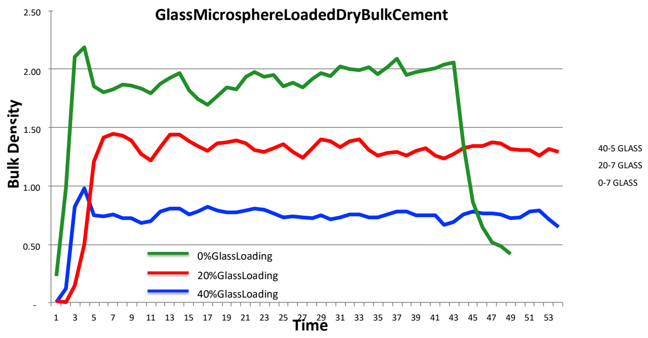


Figure 6: *Dry Bulk Blend Identification*

Dry Bulk Applications – Blend Homogenization

Another practical and critical application suited to the Red Meter is that of identifying the degree of homogenization of a specific dry blend. Dry bulk blends are often transferred between two silos or tanks, while moving as a dilute or dense phase media in order to homogenize and subsequently transport the blend. Generally, as the number of transfers increases, the blend becomes more homogenous, however it is very time consuming and difficult to ascertain the degree of homogenization using traditional discrete measurement techniques.

Figure 7 shows one such dry blend analysis. Again, the Red Meter was used to determine the bulk density and the degree of homogenization within the upper and lower critical limits of the blend, within predetermined limits. On examination of the Red Meter's Signature, the degree of homogenization is immediately apparent, showing three distinct signatures for the same blend at various stages of the homogenization process. This continuous monitoring enables Statistical Process Control (SPC), since the integrity of the blend is critical to the performance of the dry bulk material in the end use application.

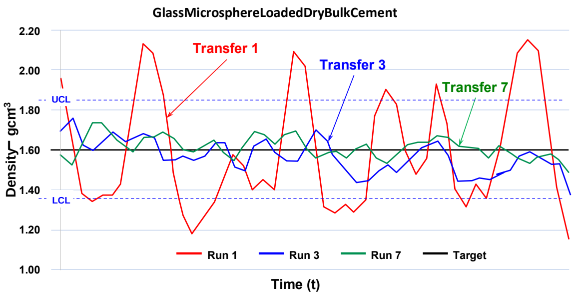


Figure 7: *Dry Bulk Blend Identification*

In this scenario, with the Upper and Lower Critical Limits established, the Red Meter can monitor the process in real time to ensure the blend consistency does not drift out of specification. If a drift or anomaly results in a breach of the process actionable limit, an immediate corrective action can be signaled by the Red Meter to divert the offending portion of the media and remedy the situation. This may eliminate the need to repeat the entire transfer at great expense, or indeed eliminate the risk of substandard materials being shipped from the plant with more catastrophic implications. In a production environment, the target SG can be set, and as the transfers progress over a steady state period, the Red Meter will indicate convergence around the mean density.

Segregation of ingredients as a result of over-mixing also poses a threat to the integrity of the blend. Segregation manifests itself as a change in peak height, which in turn indicates an increase in standard deviation. Additionally, crushing of microspheres would manifest itself as a movement of the entire signature on the y-axis, and may be accompanied by an increase in the Mean, and potentially a change in standard deviation.

Summary

The Red Meter is capable of measuring liquid, slurry and dry bulk materials on a continuous basis. It can be produced affordably in very large pipe diameter sizes, and does not interfere with the flow stream in any way.

Given its performance in liquid, slurry and dry bulk applications, the Red Meter has the potential to serve as a real time process issue detection and prevention device. With the correct processes and alerts in place around the instrument, it may also serve as a Statistical Process Control component – and irrefutable process quality recording device.