

Gamma Based Consistency Measurement in the Pulp and Paper Industry

Introduction

This technical paper describes the ConsistencyPRO as used for the measurement of percent pulp consistency in the pulp and paper industry. The ConsistencyPRO is manufactured by Thermo. Refer to the 3680 Product Data Sheet (102-136800) for complete product specifications.

For over twenty-five years, Thermo has provided measurement solutions for pulp and paper manufacturers throughout the world. Many of these solutions were developed as a result of the combined efforts of pulp and paper process engineers working with Thermo's application engineers. Many times, as is the case with the ConsistencyPRO, this combined effort has defined specific application requirements and benefits.

Pulp Consistency Measurement

The art of papermaking originated in China about 105 AD. It's impossible to say when the term consistency originated, however it's safe to say that slurry thickness has been important from the very beginning. Today, consistency control remains the most fundamental and important measurement in the pulp and paper industry. Unfortunately, consistency control systems are generally the worst performing in the mill. The desired performance is not obtained because problems are persistent and recurring in the measurement of consistency.

Without uniform consistency, the pulp and paper process is practically impossible to control. Changes in consistency must be monitored continuously, accurately, and on-line if operators, engineers and managers are to manage the process better. It is not only important to be able to sense variations in consistency, but equally important to determine the absolute value of the consistency.

How well are mills controlling their consistency? Most mills probably don't know exactly but have an idea that their consistency measurements are not very accurate and that many complaints exist about drift, frequent calibration requirements, and growing maintenance expenses.

In spite of their importance, accurate, repeatable, and reliable on-line consistency measurements are currently not obtained due to problems with existing and available technologies. These problems include furnish, flow, pressure, temperature, and PH variations.

These problems necessitate companies to look at new and emerging technologies and to put plans into place to utilize advanced instrumentation and application control solutions that already exist to manage the process better.

Consistency Definition

The term consistency, as used in the pulp and paper industry, is defined as the percentage of weight of bone dry fibrous material in any combination of pulp and water, or stock (pulp and additives) and water. It is calculated by the following formula:

$$C = (F/W) \times 100$$

Where:

C = consistency of pulp or stock slurry expressed in %

F = total weight of dry fibrous material in that amount of pulp and stock slurry

W = total weight of a particular amount of pulp or stock slurry

The above definition works especially well if the process being measured is the infeed to a refiner of beating operation where fiber mass per work unit is important. Another definition that is important for other processes is the percent total mass. The only difference in the two calculations is that the mass of other, non-fibrous, additives (i.e. ash) is included with the dry fibrous weight in the calculation. Its calculation is shown below:

$$C = [(M_f + M_a) / (M_f + M_a + M_w)] \times 100$$

Where:

C = consistency of pulp or stock slurry expressed in %

M_f = mass of dry fibrous material in that amount of pulp or stock slurry

M_a = mass of non-organic solids (i.e. ash) in that amount of pulp or stock slurry

m_w = mass of the water in a particular pulp or stock slurry

Note that the pulp and stock slurry terms are sometimes used interchangeably. A pulp slurry consist of fibrous material and water, where stock slurries primarily consist of fibrous material and water with additives such as fillers and chemicals. The amount of non-fibrous additives can be determined and used to correct the weight of the dry fibrous material in consistency calculations.

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Consistency Applications

Consistency applications vary widely with different needs, requirements, and process operations. In order to properly understand consistency applications, it is necessary to define these application groups for consistency measurements in the pulp and paper industry. Consistency applications can be split into (3) ranges.

Consistency Ranges	Percent of Application	Typical Application
Low (from 0 - 1%)	10%	Typically used in the paper mill at the wet end of a paper machine
Medium (from 1 - 6%)	75%	Typically used in both the paper and pulp mill
High (from 8 - 15%)	15%	Typically used in the pulp mill (i.e. blow line, washers, or beach plant)

Low Consistency - Most of these applications occur at the wet-end of a paper machine. This market is relatively small. There are several optical devices which measure optical depolarization, a technique which limits consistency readings to about 1%.

Medium Consistency - These are obviously the most common applications. There are two major application areas in the Pulp mill (35-40%) and in the paper mill (60-65%)

High Consistency - Typically used in the pulp mill (i.e. at the blow line, or in the bleach plant). Compared to the other applications the number of applications in this range is relatively small. The measurement here is highly critical in nature and involves approximately 15% of all applications.

Critical Applications

It is estimated that about 40% of the applications in the pulp side of the industry are critical (i.e. require more accurate, repeatable, reliable instrumentation, and hence more expensive). The remaining 60% of paper applications are less critical, where a user would not be prepared to justify more expensive instrumentation.

In the paper side of the industry, the ratio is reversed. It is further estimated that about 60% of paper applications are furnish sensitive (i.e. affected by variations in fiber lengths and blends).

The various applications in the pulp and paper areas are defined as follows. Each specific application area is further classified by how critical that control is (high, medium, or low) and the relative size of those applications expressed in percent (%) of total available consistency measurements.

Pulp Areas	Critically	Percent of Applications
Blow tank outlet continuous digester	Low	5%
Decker control	Low	5%
Brown stock washer feed	High	10%
Chlorination/Bleaching	High	10%
HD storage tanks/chest	Medium	10%
Paper Areas	Critically	Percent of Applications
Medium blend chest	High	10%
Refiner control	High	10%
Feed to machine chest	High	10%
Recycle to machine chest	High	10%
Blend chest-stock prep	High	10%
Save-all	Low	10%
Paper Machine wet end		
Repulping		

Hand Sample Consistency Measurements

Whether uniformity in consistency is achieved with new instrumentation or advanced control algorithms, it must be measured. The hand sample method of measuring consistency is the industry standard as defined by the Technical Association of the Pulp and Paper Industry (TAPPI) official test method.

T 240 om-88. The hand sample method consists of manually selecting and weighing a representative sample, removing the water, drying the sample, and weighing the remainder.

The hand sample method is inherently inaccurate, extremely labor intensive, and not acceptable for continuous control. In fact TAPPI states that their test method's repeatability is only 10%, the reproducibility is not known, and the accuracy depends on the sampling procedure. To get accurate results, sampling cannot be a casual procedure. Individuals must assume responsibility for controlling the accuracy of the sampling hardware, techniques, processing and evaluation.

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Users should also be aware of the problems inherent in the hand sampling procedure and know how to minimize them. They need to be able to manage the procedures, evaluate the uncertainty in the results, and know how to relate that information to their instrumentation and control systems. One example of the uncertainty of the hand sampling method is that it measures all solids in the mixture, not just the fiber. Many other solids may be added to the mixture including ash, clays, talcs, dyes, and other chemicals. The weight of these other additives can be determined using the TAPPI ash test method T 211 om-85.

This distinction is important. Most consistency transmitters in use today measure the fiber content of the mixture. They tend to ignore the other additives. The calibration and evaluation of these transmitters requires that an ash test be included when other additives are present. Some transmitters do respond to the additives, but they do not give the same response as they do to fibers. Their readings cannot be correlated to a measurement of fiber consistency from hand samples. Nor do they correlate to a measurement of total consistency if the percent additives changes.

Therefore, there is a need for a consistency transmitter that can accurately, repeatably, and reliably detect and measure the total mass of all fibrous and non-fibrous additives in the pulp or stock slurry.

On-Line Consistency Measurements

The paper making process requires the rapid, accurate, and on-line measurement of consistency during several stages in the process to ensure a uniform, high-quality final product. On-line, consistency can be inferred from the rheological behavior or viscoelastic characteristics of the stock via the viscosity.

Traditionally the industry has used various kinds of mechanical devices to measure pulp consistency. This type of measurement is most often conducted by measuring the mechanical shear forces of pulp passing past a sensing element. The sensing element is typically either a stationary blade submerged in pulp stock flowing at a constant rate or a torque driven propeller rotating in the stock slurry against friction caused by the apparent viscosity. Additional types of on-line consistency measurements are as follows:

- intensity of transmitted/reflected light as low consistencies
- intensity of transmitted microwaves
- intensity of transmitted ultrasonic waves
- pulp slurry conductivity
- pressure drop caused by flow through a fixed length of pipe
- load on a motor operating an agitator mixer
- head needed to maintain constant flow through viscosity tube
- depth of fluid flowing in a channel supplied from constant head
- change in depth of fluid flowing in a channel
- measurements utilizing vibrations, drainage rates and electrical resonance have also been studied

The resulting or inferred consistency measurements provide a means of control based on a characteristic that is closely related to fiber content but greatly affected by know variables such as type of fibers, velocity of stock flow, freeness, wetness, temperature, pressure, treatment, and broke addition.

This inferential measurement exhibits no long-term repeatable relationship between measurement and consistency. In addition, the short-term relationship is neither linear nor the same for different furnishes. Therefore, on-line shear based consistency measurements are only comparative measurements and should be used only to sense, trend, or track consistency variations.

Process Related Consistency Measurement Problems

Prior technology measurement devices have suffered from the problems of stock species variations, stock flow velocity, and intrusive mechanical designs because these problems produce errors, and sometimes cause physical damage, in measuring pulp consistency.

Different species of trees, or other fiber sources (i.e. recycle streams) exhibit fibers of different lengths and diameters which are characteristic of their particular origin. The handling of the fiber during the paper making process further dimensionally alters the fiber from the degree of refining, and the type of process being used (i.e. mechanical or chemical).

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Variations in fiber length and cross-section invariably cause an error in measurement. Instruments of a mechanical design utilizing shear as their principal of measurement typically exhibit a decrease in reading due to the apparent reduction in friction when measuring stock with short fiber lengths and small diameter as would be found in the hardwood species. Conversely, softwood varieties with longer, larger fibers increase the apparent friction, thus increasing the reading for any given consistency.

Optical instruments employing backscatter as their principle of measurement generally exhibit an error in the reading in the opposite direction to that of the mechanical devices. Hardwood fiber, having a larger surface area for a given consistency than softwood fiber, causes the optical instruments output to read higher due to the backscatter characteristics generally associated with an increase in consistency.

Velocity of the stock slurry also causes measurement error when one is attempting to measure consistency. Usually, consistency measuring devices cannot detect a difference between a changing flow rate or consistency, requiring that some compensation be made for the effects of flow velocity.

Unfortunately, when pulp gets into the seal of a rotating device, it is very abrasive and causes seals to deteriorate very rapidly. Also, at the start-up of a pulp flow line, the pulp flow can carry with it large dried plugs of pulp. When these plugs of pulp are driven through process pipes, they can cause considerable physical damage to any obstruction or measuring device mounted within the pipeline.

Blade Style Consistency Transmitters

Average range of application is 1.5 to 6 or 8% consistency (non-critical applications). Blade transmitters utilize shear force technology and hence suffer from problems associated with furnish variations, flow rate, pressure, ash addition. In addition, blade units are intrusive devices and require additional installation, maintenance and calibration resources (i.e. by-pass lines, additional instrumentation, process shut-down, frequent bench-top calibrations, and expensive hastelloy and titanium materials).

Optical Consistency Transmitters

Optical consistency products sell for \$8 to \$15,000, are extremely accurate, require small sample lines with minimal flow, and are very susceptible to build-up and hence require frequent calibrations. Because optical measurement are extremely accurate and are not sensitive to color or brightness, they are most often utilized in head box and fiber recovery applications.

Many mills readily acknowledge the frequent calibration requirements, but trade frequent calibration for exacting accuracies as needed for head box and basis weight controls.

Microwave Consistency Analyzer

Microwave measurement of consistency claims a total consistency measurement which is independent of grade or wood species. This technology currently measures ranges over 1.5%.

The microwave analyzer does provide many of the capabilities that are lacking in other technologies. These capabilities result in a high cost system in addition to the cost associated with its intrusive process installation. The system performance is also limited by process pressure, conductivity and pH level. Due to its intrusive nature this technology may require the use of expensive materials such as Hastelloy in some of its components.

Measurement Problem Summary

In spite of their importance, accurate, repeatable and reliable on-line consistency measurements are currently not obtained due to persistence and recurring problems with available technologies. These problems include sampling, furnish, flow, pressure, temperature, and pH variations. These problems necessitate companies to look at new and emerging technologies from a strategic perspective and to put plans into place to leverage advanced instrumentation and application control solutions to manage the process better.

For these reasons users have had a lot of maintenance problems associated with the mechanical types of sensors, and hence they are still looking for other types of devices which are potentially more reliable and easier to use.

Therefore, there is a need for a consistency measurement device which is accurate, repeatable and reliable that is not affected by or is capable of easily compensating for variations in fiber size, stock flow velocity, pressure, temperature and pH level.

ConsistencyPRO Scintillation Based Consistency Transmitter

The ConsistencyPRO redefines the standard for accurate, on-line pulp consistency measurement and eliminates the problems of typical of other consistency devices.

The ConsistencyPRO provides non-intrusive, gamma based measurement that reads pulp consistency in percent solids with a proven repeatability of 0.1% consistency and accuracies up to 0.1%.

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A proprietary temperature correction algorithm and additional performance testing have been incorporated to provide the higher quality control and applications performance necessary for highly demanding consistency applications.

To ensure system integrity, the ConsistencyPRO combines an improved scintillation based detector with the power of a HART SMART transmitter into a ruggedized explosion-proof, three compartment housing.

Since the system is completely non-intrusive, it is not affected by furnish type, flow variations, temperature swings, pressure changes, pH, viscosity, corrosiveness, or abrasiveness. The ConsistencyPRO simply mounts around an existing process pipe. This eliminates the need for expensive pipe modifications, by-pass lines, and process downtime during installation.

Advanced scintillation technology, proprietary consistency algorithms, rugged packaging, and HART Smart communication combines advanced instrumentation and application solutions that allow pulp and paper companies to manage the process better.

Principles of Operation

The ConsistencyPRO continuously measures pulp consistency through the proven technology of gamma beam attenuation. The ConsistencyPRO's detector/transmitter mounts on a process pipe opposite a gamma source housing using a pipe saddle.

The source housing, containing a single gamma source capsule, is constructed of either carbon steel or stainless steel and is filled with lead for shielding. The source housing directs a beam of gamma energy through the process pipe into the detector/transmitter. The gamma beam is shielded by a lockable, two-position (open/closed) shutter mechanism.

The ConsistencyPRO contains a scintillator that when subjected to the gamma beam, produces photons of light, which are in turn converted to an electrical signal through a photo-multiplier tube. The number of pulses from the scintillator sensor is directly related to the intensity of the gamma energy received. These pulses are conditioned, counted, and scaled by the transmitter's on-board microprocessors to provide accurate, repeatable, and reliable consistency information.

The amount of gamma energy which passes through the pipe is inversely proportional to the consistency of pulp stock within the pipe. The ConsistencyPRO's output is processed digitally and converted to a standard 4-20mA analog signal. The signal can also be provided in digital format using the HART® (Highway Addressable Remote Transmitter) communications protocol either superimposed upon the 4-20mA output or via a separate intrinsically safe local connection at the transmitter.

Accurate

The ConsistencyPRO uses advanced scintillation detection and precise drift compensation to produce a consistency measurement system with superior performance. Scintillation detection provides a typical repeatability of ± 0.0015 SGU using low radiation fields. Enhancements to this value can be made through longer time constants or larger radiation effects.

Drift caused by source decay is compensated for and ambient temperature shift is negligible, providing greater accuracies than traditional sodium iodide crystal-based systems. This drift compensation, when combined with the scintillation detector produces accuracies up to ± 0.0001 g/cc depending upon field calibration reference data and system configuration.

Reliable

The ConsistencyPRO is designed for dependability and long life, featuring a rugged housing, reliable electronics, intrinsically safe communications, and a broad range of hazardous location approvals.

The rugged housing (epoxy paint coated aluminum alloy) is water and dust-tight. Its three compartments are self-contained, making the field wiring terminals accessible without exposing the electronics to ambient conditions.

The electronics used in the transmitter are not affected by fluctuations in the power supply. If power is interrupted, the electronics stores the configuration data in non-volatile memory. Upon re-establishment of power, the transmitter is immediately fully functional.

Communication with the Fisher-Rosemount Model 275 Handheld Communicator is conducted through a separate, intrinsically safe terminal or via the 4-20mA loop.

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Flexible

The ConsistencyPRO provides flexibility by automatically adapting to the supplier power source, accepting inputs for temperature compensation and allowing user-defined adaptive damping and units of measurement.

The ConsistencyPRO's electronics automatically adapt to almost any AC or DC power source supplied and switches to backup DC power when provided. All voltages from 90 to 250 Vacs, 50/60 Hz and/or 18 to 36 Vdc are accepted.

Through the use of an optional 3-wire RTD or 4-20mA temperature transmitter, the ConsistencyPRO can compensate for density changes caused by fluctuation in temperature.

Easy To Use

The ConsistencyPRO's menu-driven interface, continuous self-diagnostics, and modular construction make operation easy for even the novice user. The menu-driven interface displays all communications between the ConsistencyPRO and Model 275.

Self-diagnostics continually update the system status to the Model 275's display. Should an error be detected, diagnostic messages will be displayed to assist the user in locating and correcting the problem.

In the unlikely event that a fault is detected within the electronics, the electronics module or sensor can easily be replaced in the field without compromising accuracy.

Communications Features

The ConsistencyPRO can be interrogated and configured locally or remotely by using the Fisher-Rosemount Model 275 Handheld Communicator. The Model 275 can be used to configure the ConsistencyPRO from any wiring termination point in the 4-20mA loop, including the control room. Communication with the Model 275 does not interrupt the transmitter output signal. In addition, the user can enter configuration data into the Model 275 while not connected to the ConsistencyPRO. This data is stored in non-volatile memory, and can be downloaded later into one or more ConsistencyPRO's in the field.

When the Model 275 is connected to the transmitter output loop, it identifies the ConsistencyPRO and offers a choice of options including on-line configuration, off-line configuration, system formatting or calibration, and diagnostic testing. Monitoring of the process variables can be achieved at any time by the user.

Calibration and Referencing

The referencing and calibration of the ConsistencyPRO can be conducted in one of two methods.

The first is a Quick Start procedure which requires only one sample. Through Thermo's testing and experience with gamma measurements the Quick Start procedure has been developed and is probably one of its simplest start-up procedure of any consistency measurement technologies. In summary the ConsistencyPRO is referenced on the existing pulp stock consistency.

During the reference cycle which typically lasts less than 2 minutes, a sample is drawn and forwarded to the lab for analysis. Once the lab sample is returned the sample valve is directly entered into the ConsistencyPRO. The calibration is finished.

The second method consists of varying the process to obtain different consistency levels. The reference and first calibration point are based on a low consistency process value. The process is varied to obtain as low a consistency value as possible. The reference cycle is initiated and a sample is drawn and analyzed. The process is then varied to as high a consistency value as possible. A sample is drawn as a sample signal is read by the ConsistencyPRO. Once both physical samples are returned the calibration curve is set up in the ConsistencyPRO.

In most cases the Quick Start procedure will provide more than satisfactory results with minimal effort although either start-up procedure may be used.

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The stability and accuracy requirements for pulp consistency measurement applications is more demanding than most other density applications. The ConsistencyPRO is specially designed for consistency measurements and assures that these demanding requirements are met. Additionally, the ConsistencyPRO incorporates a proprietary temperature correction algorithm for consistency measurements to ensure the highest performance available.

Thermo worked with Weyerhaeuser Technical Center in Federal Way, Washington for testing and documenting the ConsistencyPRO's performance. Weyerhaeuser presented its report at the 1994 TAPPI Process Control Symposium. Copies of the report are available through TAPPI or Thermo. The highlights of this report are shown below:

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- Nuclear based CS measurement is theoretically sound and is a practical method for CS measurement
- Furnish type has little or no effect on ConsistencyPRO transmitter
- Process variations in flow rate, pressure, and pH have little or no effect on ConsistencyPRO transmitter
- Process temperature compensation circuit was modified to deal with 2-phase water/pulp mixture (due to the non-linearity of water density w.r.t. temperature).
- Entrained air did effect output but orientation and higher process pressure (50psi test condition) minimized this effect.
- Ease of installation and limited calibration/maintenance requirements of non-intrusive device superior to completion.

As today's pulp and paper companies strive to become world-class suppliers, mills are increasingly focused on final product quality. This is accomplished through incremental quality improvements with high-speed, high-accuracy process measurement solutions coupled with advanced technology.

Additionally, environmental pressures are forcing the industry to radically modify some age-old operating procedures, while enforcing stringent measurement and control limits on others. This operating climate places a premium on high-accuracy measurement devices with built-in flexibility and ease of configuration.

From recovery boilers to continuous digesters, and from pulping and bleaching to stock preparation and paper machine control, the ConsistencyPRO provides the complete process measurement and advanced controls solutions for the papermaking industry.

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