Process automation of phenolic treaters

Robert J. Engel

ABSTRACT: An increasingly competitive business environment is leading laminators to seek higher efficiency and improved quality through the application of process automation technology. Phenolic treaters, due to significant throughput and challenging quality objectives, are well suited for the application of this technology. Current system technology encompasses scanning on-line quality measurements, total line control, and advanced quality analysis and reporting.

KEYWORDS: Automation, continuous process, on-line measurement, polyphenolics, process control, quality control.

On-line quality control

On-line sensor technology is available which continuously monitors the physical properties of the substrate material as it progresses through treating and drying processes. Considerable improvements in product uniformity are obtainable by integrating these continuous quality measurements with supervisory and optimization controls.

Treater control

The performance of the phenolic treater, shown in **Fig. 1**, is monitored by a differential measurement technique. Nuclear basis weight sensors (**Fig. 2**) are utilized to measure the weight per unit area of the substrate and the weight of the saturated substrate.

Nuclear sensors monitor the attenuation of beta particles by the web. A nuclear isotope transmits beta particles toward the web. These particles are transmitted, absorbed, or deflected by the web. The concentration of beta particles which enter an ion chamber receiver on the opposite side of the web can be related to the weight per unit area of the material by an exponential relationship as defined in Beer's Law. On-line compensation for temperature variations, drift, dirt, and nuclear decay, combined with sensor optics designed to eliminate sensitivity to pass-line variations and the source/receiver misalignment which can occur as the sensors traverse, allow accuracies as high as 0.25% of reading.

Individual sensor readings are obtained every 0.050 in. of sensor travel. Individual readings are allocated into measurement segments by a microprocessor-based controller located in the scanner frame. Successive profile measurements are statistically smoothed to eliminate sensitivity to short-term machine-direction variability.

Smoothing techniques essentially produce a "true" cross-direction profile which does not represent machine-direction variations contained in a single diagonal traverse of the web.

Same-spot measurements are used to eliminate sensitivity to formation in the substrate material. This technique ensures that the wet scanner and the substrate scanner traverse exactly the same spot on the web, even as line speed varies, by closely coupling the launch time and scan speed of the wet scanner to that of the upstream scanner. Since each sensor traverses exactly the same point on the web, the differential calculation is unaffected by point-to-point variations in the substrate. Scanner synchronization of two milliseconds is possible using a local area network connection between scanners which operates at 10 megabaud.

The substrate measurement is subtracted from the wet scanner measurement to produce a differential weight profile, which represents the quantity of resin added during saturation. This measurement allows continuous feedback control of the treater to maintain uniform resin contents.

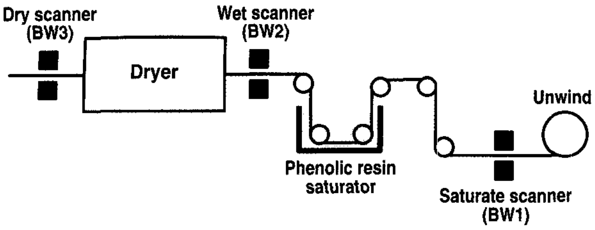
Retained solvents

Retained solvents measurements (**Fig. 3**) can be obtained by applying a differential measurement technique across the dryer. The wet scanner measurement is coupled to a dry scanner measurement which is located at the outlet of the dryer. The differential weight calculation relative to the known percent solids of the resin indicates the quantity of solvents released during drying.

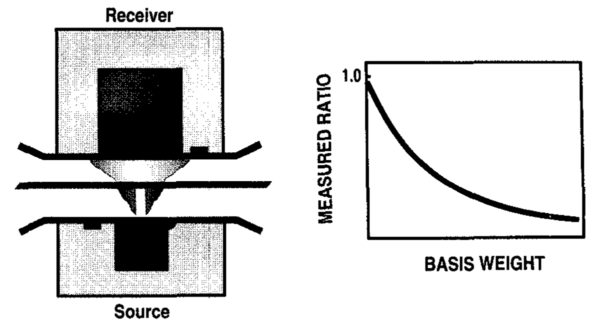
Retained solvents is expressed by the following equation:

Engel is marketing manager for Eurotherm Gauging Systems Inc., 46 Manning Rd., Billerica, MA 01821.

1. Phenolic treater



2. Nuclear basis weight sensor



Retained solvents =

$$(BW2 - BW1)(1 - \% \text{ solids}) - (BW3 - BW2)$$

where

BW1 = substrate basis weight

BW2 = wet basis weight

BW3 = dry basis weight.

Cure

Recent innovations in infrared sensor technology provide a mechanism for the on-line measurement of cure. Full-spectrum infrared (FSIR) techniques continuously monitor the full near-infrared spectrum (1.35–3.4 microns) to identify variations in spectral absorbance. Absorption of infrared energy can be related to the cure of the material.

FSIR technology utilizes an analytical technique known as chemometrics to define a calibrated measurement from an array of spectral absorbance data. Factor analysis techniques allow a matrix of calibration data to be defined which converts a spectrum of absorbance (or transmittance) data into one or more measured components. In the case of the cure measurement, a single physical attribute is measured. This technology can also produce moisture or retained-solvent measurements simul- taneously.

Advancements in microprocessor technology, which allow spectral processing to be performed in the sensor itself, provide a continuous on-line measurement. As a result, cure profiles can be displayed in a manner generally associated with the basis weight profiles measured by nuclear beta sensors.

The cure measurement can be used to optimize speed and dryer temperatures. Since cure may be affected by several process variables, and cure may interact with other quality parameters such as retained solvents and resin content, statistical process control (SPC) charting techniques are well suited for monitoring of cure in real time.

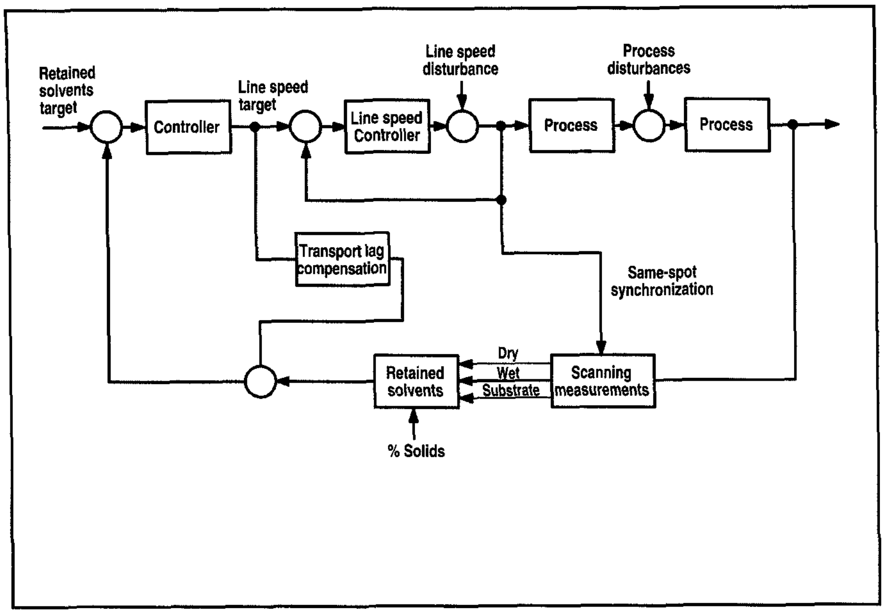
An on-line scanning temperature sensor, mounted on the dry scanner, provides additional information which can be useful in evaluating the performance of the dryer and the relationship between cure and solvent retention.

Nominal controls

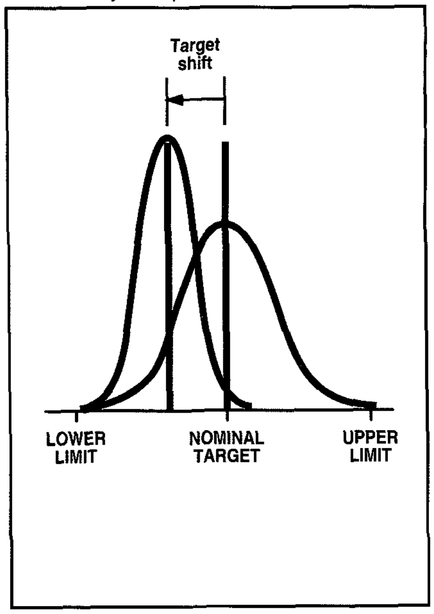
Nominal controls automatically maintain a uniform control parameter according to feedback from on-line quality measurements. This control couples a control actuator to each quality parameter. For example, line speed may be utilized as the control parameter for retained solvents, since the dwell time in the dryer affects the quantity of solvents released from the web. In this case, a cascaded control strategy is applied. The error calculated by comparing the current retained-solvent value to the target results in correction to the line-speed target. The line-speed controller actually calculates the appropriate line-speed output to reach the new target. The cascaded strategy improves performance and simplifies tuning by partitioning a complex control strategy into two simple feedback loops, each of which can be tuned for maximum performance.

Feed-forward techniques may also be required when a single actuator affects multiple quality parameters. For example, adjusting line speed may affect retained solvents as well as the resin content. An automatic control strategy which utilizes line speed to regulate retained solvents must also feed-forward corrections to the treater to maintain uniform resin content. Feed-forward strategies, therefore, require an independent actuator for each affected parameter (line speed for retained solvent and a treater actuator for resin content).

3. Retained solvents control



4. Material yield optimization



Optimization controls

Optimization controls convert the quality improvement associated with nominal controls into a direct and tangible economic savings for the processor. Improvements generated by optimization controls generally fall into two categories: material yield optimization or throughput maximization.

Material yield controls continuously monitor the variability of the control parameter, resin content for example, and shift the target towards the lower control limit. This gradual target shift, shown in **Fig. 4**, is typically performed at the end of each scan. The variability of the resin content is analyzed at the end of scan to ensure that no material violates the lower specification limit. In the event that material does fall below the lower limit, the target is immediately shifted upward. Material yield controls improve yield by continually optimizing the operating target relative to the lower limit. Precise measurement coupled with material yield control can generate a savings of hundreds of thousands of dollars each year on a typical phenolic treater.

Throughput controls maximize the throughput of a line while ensuring that no parameters violate control specifications. For example, line speed is automatically ramped while resin content, retained solvents, and cure are continuously monitored. This strategy increases throughput to the maximum operating limit while ensuring that no quality parameters exceed acceptable limits.

Integrated instrumentation

The computational power and high-resolution graphics, coupled with the trend toward microprocessor-based controllers, provides a mechanism for cost-effectively integrating all process instrumentation into the supervisory gauging system. This results in functionality which has been traditionally associated with distributed control systems at moderate incremental costs over a stand-alone gauging system.

Dedicated process controllers are applied for control of the dryer. Digital drive systems maintain line speed and correct tensions between drives. Programmable logic controllers support equipment, logic, and interlock functions.

Local area network technology is utilized to integrate the various intelligent devices. While some controls manufacturers offer direct Ethernet network connections, in most cases a microprocessor-based device acts as a bridge to the network. These devices provide a serial communications port for interfacing to the controller, an Ethernet adapter for peer-to-peer network communications, and a software configurable program device for protocol conversion (**Fig. 5**).

Integration of instrumentation generally encompasses recipe management, monitoring, trending, alarming, and reporting functions. By combining all machine control functions into a single system and operator interface, the condition of the machine can be more closely monitored.

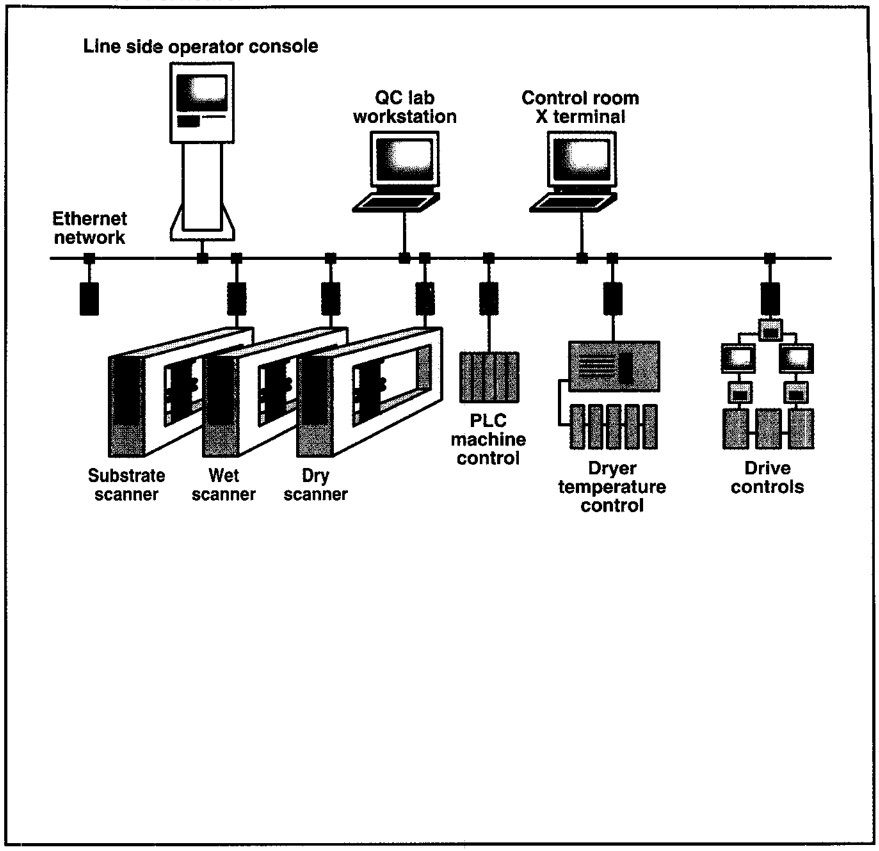
The operator displays are designed to provide all relevant process information from the main system operator interface. Operators may view process data graphically or numerically. Graphics representations of the line are often used to create an intuitive interface. Operators are immediately notified of an alarm, whether related to on-line quality measurements or a distributed process controller, to minimize the time it takes to correct off-quality conditions.

Total quality management

Statistical process control (SPC) and quality control (QC) techniques are widely accepted for monitoring the performance of key process and product attributes. Comprehensive control charting is now available in line-side operator control stations to automatically identify trends which are statistically abnormal. SPC alarms are tied into the overall alarm structure of the supervisory system.

The Shewhart chart is a common technique for control charting. With this technique, a number of samples are acquired at fixed intervals. The average (X bar) and range (R) of each sample set are plotted. Nonrandom trends or shifts, as well as excessive range within a given sample set, indicate degradation in the performance of the process and the product. The automation of this analysis ensures that it is performed accurately and reliably for all the appropriate variables, without increasing the staffing requirements on the line. Shewhart charting is especially appropriate for product attributes, such as cure, which cannot be easily controlled with conventional feedback techniques.

5. Process control network



Laboratory integration has been further enhanced with improved networking and display protocols. The X Window System in particular has promoted close integration of laboratory entry and analysis, by allowing distributed terminals and workstations to have full access to all displays originating from the line-side system. The X Window System is a nonproprietary display protocol which allows a terminal or workstation to access applications and displays operating on another station. In the case of a QC lab workstation, a lab technician can access an SPC chart on a line-side system without affecting the primary operator interface.

Information management

The application of general-purpose computers for supervisory control has increased the reporting capabilities. Multi-user, multi-tasking operating systems now allow a supervisory computer to collect information for archiving and analyses. Multi-user environments allow this data to be accessed from remote terminals while the line continues to operate.

The general acceptance of off-the-shelf computers and operating systems for supervisory control has also allowed the integration of commercially-available software applications for database, reporting, and analysis. For example, relational database manager system (RDBMS) technology can be applied for recording process data, alarms, events, and defect information. The RDBMS structure provides a mechanism for easily accessing and sorting appropriate information at a later time. For example, a summary of retained-solvent values for a particular product recipe can be analyzed according to the specific resin supplier. These advanced reporting tools provide processors tools which allow better understanding of the process with minimal effort.

The trend toward integration of distributed process controllers, advanced reporting, and continuous quality analysis is being driven by the increased certification requirements and industry's move toward "total quality management." With these tools, laminators are in a position to produce a higher quality product at a lower cost and cater to evolving customer demands for quality traceability and accountability.

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