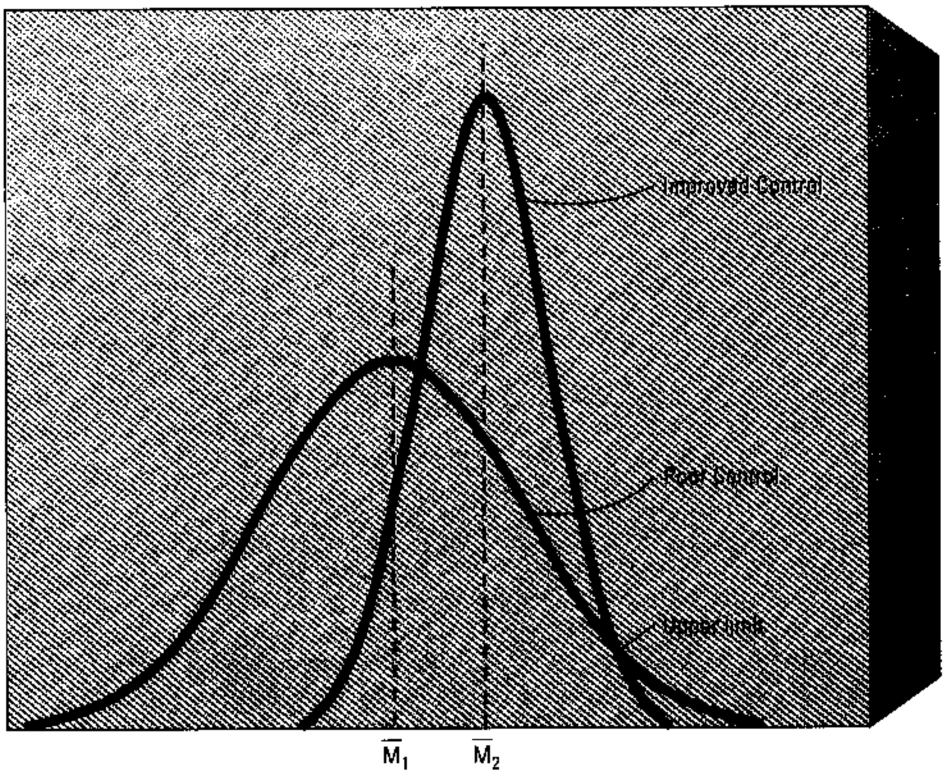
Improve Dryer Control



■ *Figure 1. Improved control results in a narrow moisture content distribution.*

Understand the types of dryer control, their advantages and limitations, and their applications.

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Industrial drying is an energy-intensive operation, consuming approximately one quad (10^{15} Btu) of fossil fuel energy annually in the United States. Dryer efficiencies, defined as the ratio of theoretical energy required for evaporation to the actual energy consumed, typically range from 40% to 45%, but may be as low as 10%. A reduction in U.S. dryer energy consumption of just 2% equates to savings of approximately four million barrels of oil per year. Consequently, significant rewards await those who improve dryer efficiency.

In recent years moderate advances in drying have been achieved. However, drying is still not well understood, due mainly to the complexity involved in the simultaneous transfer of heat, mass, and momentum during the process. Modeling has increased our knowledge, but many models are cumbersome, dryer- or product-specific, and require data that are either unavailable, suspect, or outdated.

Escalating energy costs and more intense global competition provide the impetus for continued efforts in improving drying efficiency. At least one international publication (*Drying Technology*) is devoted exclusively to the advancement of drying technology. Additionally, a consortium between the Univ. of Texas and Texas A&M Univ., called The Texas Drying Research Consortia (TDRC) — believed to be the first of its kind in the U.S. devoted exclusively to drying research — was formed in 1988. And, the Separation Processes Service (SPS) in the U.K. is an international resource for continuous convection dryers. [For more on these and other sources of information, see the sidebar in the article by Moyers, p. 34-40. — Editor] These and additional efforts for improving drying will continue. However, unless accompanied by corresponding improvements in dryer control, a substantial portion of these improvements may be lost.

Dryer control

Dryer control, defined as the ability to dry a product to a desired moisture content (MC) with acceptable variation, has not progressed concurrently with improvements in drying and dryer design. This lag is attributable to three factors:

- the lack of emphasis on product quality in the past;
- an apparent lack of knowledge of the important part dryer control plays in product quality and drying efficiency; and
- the lack of a good reliable method for sensing product MC inside the dryer.

Now, however, competition demands improved product quality and maximum energy efficiency. All areas of drying — including dryer controls — must be investigated more closely.

Experience gained during the replacement of a number of existing dryer control systems indicates that many manufacturers overdry their products because of limitations imposed by present dryer control technology. Figure 1 compares dryer exit MC distributions for poor and improved dryer control. Poor control results in a distribution with wide MC variations, whereas improved control results in a narrow distribution. The upper MC limit of each distribution is essentially the same, demonstrating that with good control the overall average MC may be increased without increasing the amount of wet product.

When a dryer is poorly controlled (that is, when it is unable to maintain a narrow moisture distribution), drying must proceed at a lower overall average MC, with consequent loss of production, quality, and thermal efficiency (Btu/lb of water removed). The economic consequences of this are significant. For example, improving the control of a large tonnage rotary dryer processing agricultural products and increasing the average MC by 1% would result in approximately $500,000/dryer/yr additional revenue.

In most cases dryer control is hampered by the lack of reliable and timely feedback of product moisture content data. Use of MC surrogates, such as exit vapor or product temperature, as the controlled variable usually results in poor control, due to the low correlation between the surrogate and the actual product MC.

For batch dryers, it would be advantageous to know the MC of the product vs. time in order to shut down the dryer when the set point MC is reached. For continuous dryers, knowing the MC of the product before it leaves the dryer would enable timely corrections in dryer conditions, which would yield a product MC depicted by the curve labeled "Improved Control" in Figure 1.

Due to the hot, corrosive, dirty, and space-limited environment inside most dryers, it is impossible or impractical to place conventional moisture sensors inside dryers. In cases where it is possible, the sample size may be too small to be representative. In some cases, the product's physical and chemical properties prevent accurate MC measurements with sensors using conductivity, capacitance, microwave, infrared, or other such techniques. Clearly, a universally applicable and practical means for measuring product moisture content inside dryers would enable significant improvements in dryer control.

Dryer control methods

Until the advent of process computers, manual and automatic feedback systems were the most commonly used methods for dryer control. Many, in fact, are still in operation in older plants.

The availability of process computers, advances in dryer modeling techniques, and improvements in sensor technology have increased the use of control systems combining feedforward and feedback loops. The recent development of a dryer control system that uses only temperature sensors for measuring MC before the product leaves the dryer is significantly improving dryer control. It will replace feedforward and feedback loops with a single loop that senses product MC just before the dryer exit.

Manual feedback control

Manual feedback control, although somewhat outdated, exists in many applications.

Figure 2 represents a single-zone dryer operated with constant feed and is typical of such dryer types as flash, spray, fluidized-bed, belt, conveyor, rotary, and so on. At some point downstream of the dryer exit, an operator measures MC and mentally compares the measurement to the desired value. He or she then makes adjustments to the energy input based on the difference between the desired and the actual MC values. Alternatively, the fuel rate may be held constant and the feed rate manipulated, or both energy input and feed rate may be manipulated to maintain the desired MC.

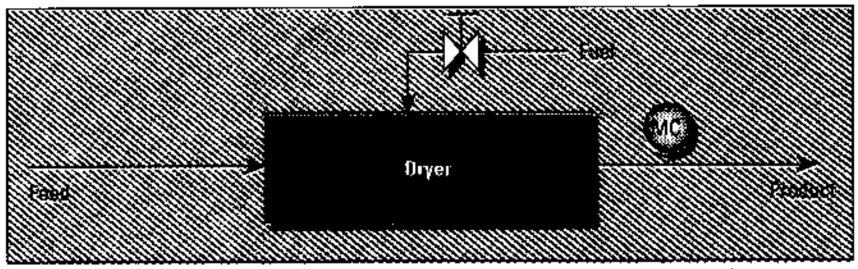
Such open-loop systems are simple, less expensive, and require less expertise to operate than more advanced control systems. However, they are not responsive to process disturbances and are not used when good control is required. MC ranges as much as ±8 MC units for such systems.

Closed-loop feedback control

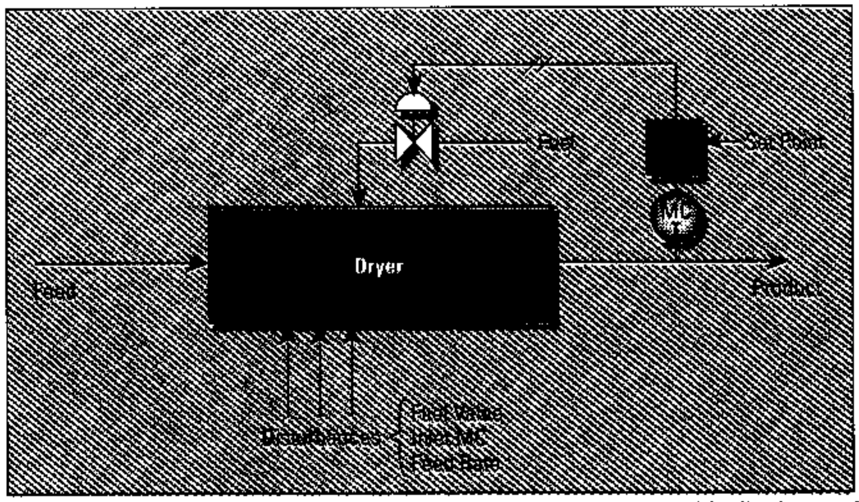
Feedback dryer control, depicted in Figure 3, employs a sensor to measure the moisture content or a surrogate (the controlled variable) at a point downstream of the dryer. This value is transmitted to a controller, which compares it to the desired set point value and uses the difference (error) to calculate the amount of change in energy input (the manipulated variable) required to bring the MC back to the set point value.

If this adjustment in manipulated variable is automatic, the system loop is closed. If not, the system is open-loop and an operator must manually adjust the fuel valve, as discussed previously.

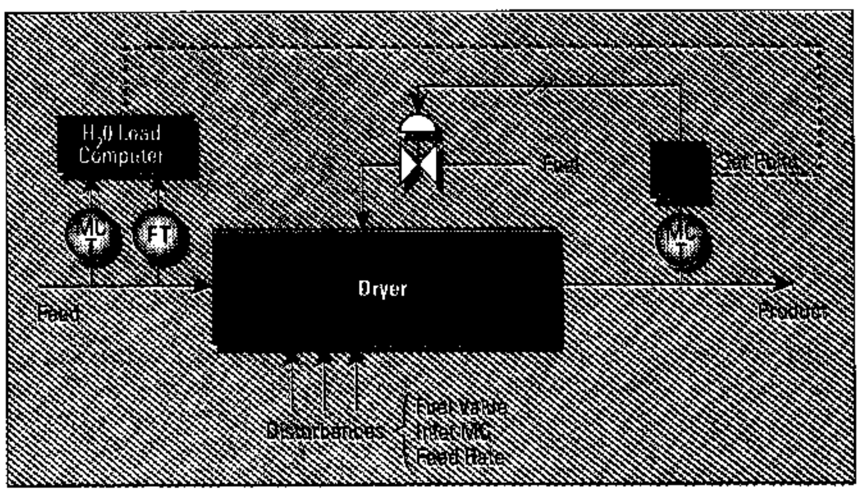
Closing the loop improves upon manual feedback control by speeding up the return of controlled variable data upon which to make the control decision. MC ranges from about ±4–5 MC units and costs are approximately 1½–2 times those of a manual feedback system. And because it is more complex than a manual system, maintenance costs are higher as well.



■ *Figure 2. Manual feedback control is the simplest form of dryer control.*



■ *Figure 3. Closed-loop feedback control is an improvement over manual feedback control.*



■ ***Figure 4. Feedforward control accounts for disturbances not addressed by feedback systems.***

Feedforward control

Feedforward control systems include sensors for measuring the effect of disturbances to the drying operation not accounted for by feedback systems. Figure 4 illustrates feedforward control added to the feedback system of Figure 3 to correct for variations in evaporative load to the dryer. Here, a disturbance is sensed and the necessary correction in the manipulated variable, in this case the fuel rate, is made.

Such systems require additional sensors, as well as a thorough knowledge of the relationship between disturbances and the manipulated and controlled variables. Acquiring such knowledge escalates the operating and engineering costs.

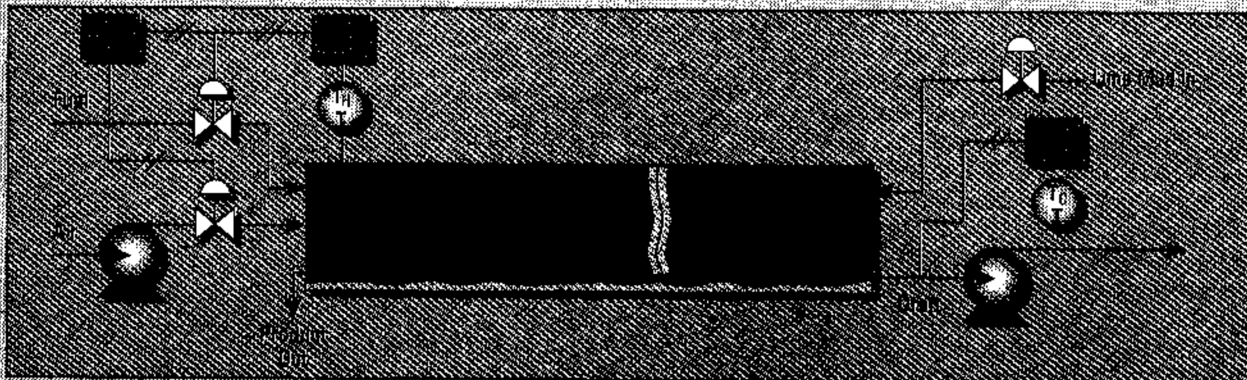
To measure the disturbance caused by variations in entering evaporative load, it is necessary to include a feed rate sensor and transmitter and a moisture sensor and transmitter at the front end of the dryer. A computer-generated material balance gives the theoretical amount of water to be evaporated and the amount of fuel required for

Eliminating Errors and Noise

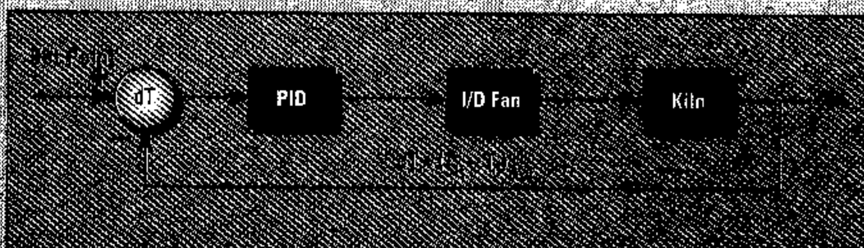
Application of the patented Delta T temperature-drop control system to the drying zone of a paper mill lime mud kiln is an example of how interactive loop tuning errors and noise may be minimized or eliminated using this new approach to dryer control. The concept can be extended to various types of single-stage dryers, such as flash, rotary, spray, and so on, where exit vapor temperature is the controlled variable.

Figure A shows schematically a lime mud kiln control using primarily hot end temperature (HET) and cold end temperature (CET) loops. The HET is maintained at approximately 2,200°F by manipulating the fuel valve, and the CET is maintained at approximately 325°F by manipulating the main draft damper. In practice these two loops are interactive and should be decoupled.

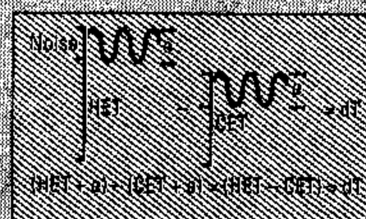
Another problem associated with such interactive loops is noise and tuning errors associated with the HET loop that are transferred (erroneously) to the CET loop as the evaporative load changes. Figures B and C demonstrate how substituting the variable ΔT (HET – CET) for the variable CET eliminates this problem through subtraction.



■ *Figure A. Schematic control system for a paper mill lime mud kiln.*



■ *Figure B. Error and noise are eliminated by temperature-drop control.*



■ *Figure C. Substituting ΔT for CET eliminates noise and tuning errors.*

comparison with the amount of fuel actually being consumed. The difference is used to correct the manipulated variable. However, in reality it is not that easy. If the drying time is long or the dryer has multiple zones, there is a delay in response time between adjustment in the manipulated variable and its effect upon the controlled variable (MC).

To meet higher quality and efficiency demands, dryer control systems have become more sophisticated and costly. For example, the system of Figure 4 requires an additional moisture sensor and transmitter, a feed rate sensor and transmitter, and a process computer to improve the moisture distribution of the product. As quality and efficiency demands increase further, still more loops are added to correct for remaining disturbances.

Costs for feedforward systems range from 3–4 times the costs of manual feedback systems. However, MC distribution is improved by ±2–2½ MC units.

Feedforward loops are necessary in part due to the time lag in obtaining exit MC data. If it were possible to measure MC inside the dryer, feedforward loops would be unnecessary, since the effect of all disturbances would be lumped into the MC measured inside the dryer and could be corrected before the product left the dryer.

Temperature-drop model

An alternative dryer control system enables determination and control of MC at any appropriate point along or inside batch or continuous dryers before the product leaves the dryer. For continuous, convective dryers it is based on the model

$$M = K_1(dT)^q - K_2/S^p \qquad (1)$$

which relates product moisture content (M) to the temperature drop (dT) of hot air before and after contact with the product and the dryer speed or production rate (S). K values and exponents are constant for a given product and dryer.

For batch dryers, the model becomes

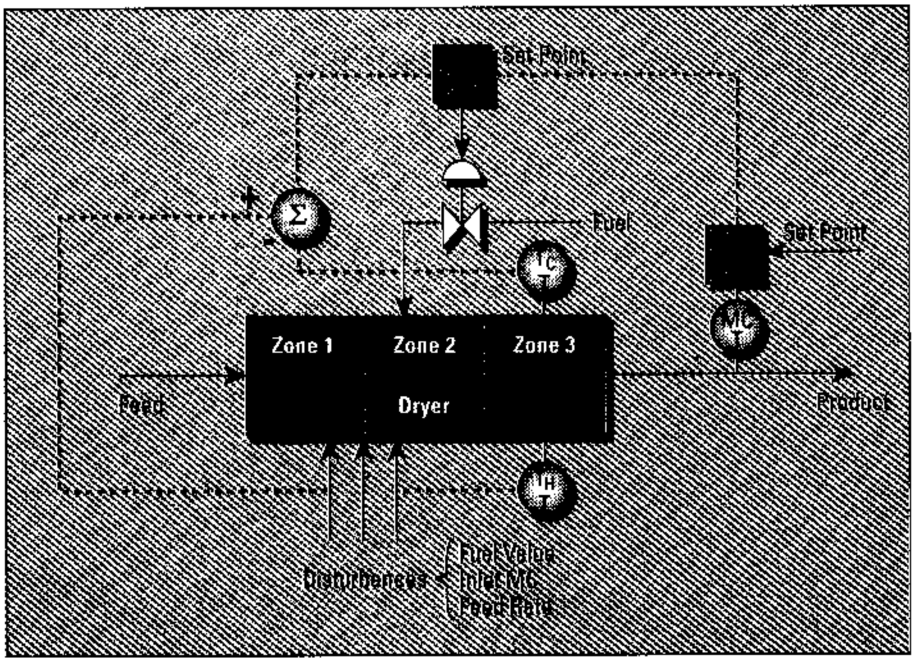
$$M = K_1(dT)^q - K_3(D_t)^r \qquad (2)$$

where D_t is the drying time.

The ability to determine the moisture content at any point along or inside a dryer simply by sensing two temperatures is important because it enables the use of simple, accurate, off-the-shelf sensors, such as resistance temperature detectors (RTDs) and thermocouples, inside dryers where it is impossible or impractical to install conventional moisture sensors.

The control variable is ΔT, which represents a temperature difference. Its exact definition depends on the type of drying. For example, it is usually defined as the change in the temperature of the air before and after contact with the product (dT, as in Equations 1 and 2). In batch drying it may be defined as the temperature of the entering hot air minus the temperature of the air leaving the dryer. And in a dryer using conductive heat transfer, it is the difference in temperature between the hot conductive heat source and the surface temperature of the product leaving the hot surface.

The model lumps all variables affecting drying and the drying rate into the single variable, ΔT. Let us assume that the control system of Figure 4 is a cross-flow, three-zone layer dryer. If the water load to the dryer varies for any reason, this variation will be detected at the ΔT control station in time for sufficient adjustment to be made in the manipulated variable to maintain the MC of the exiting product at its set point value. Such a ΔT loop eliminates the need for feedforward loops to handle disturbances in feed and fuel flow. A two-loop, cascaded control system with ΔT as the outer loop controlled variable, as shown in Figure 5, may be applied in this situation.

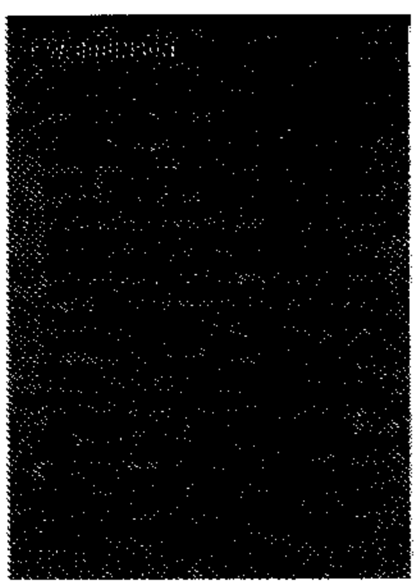


■ ***Figure 5. This two-loop cascaded control system is based on the temperature-drop drying model.***

Costs for a temperature-drop control system are about 1½–2 times the costs of manual feedback control. The product MC range is ±1–2½ MC units. The system is somewhat less complex than a feedforward/feedback system.

Batch dryer control

Present batch dryer control systems use surrogates such as vapor temperature as the controlled variables for determining when to shut down the dryer. The low correlation between surrogate and product MC often requires shutting down the dryer after the set point has been reached and taking a sample for MC analysis. The dryer is restarted if the MC is above the set point value. It would be expected that an equal number of batches would be overdried as would be underdried with such a control system. This problem of low correlation between MC and controlled variable is exacerbated by the lack of constancy from batch to batch in source temperature, batch weight, and initial MC, and in the physical and chemical properties of the product affecting diffusion of water to the surface. A control system is needed that eliminates such errors.



The temperature-drop method enables calculation of drying rates and rate-of-change in drying rates for use as the controlled variables. Such variables significantly improve control of endpoint MC because they are independent of dryer and process variables.

Batch drying, for example, in such industries as pharmaceuticals, lumber, chemicals, foods, and so on, utilizing dryer types such as fluidized-bed, tray, and vacuum, are good candidates for application of the temperature-drop method. Presently, sev-

Table 1. Comparison of dryer control methods.

Control Method	Tradeoffs	Relative Cost	MC Spread
Manual Feedback	Simple to operate Relatively inexpensive Simple to maintain Wide MC Distribution	Base	[illegible] MC units
Automatic Feedback	Simple to operate Relatively inexpensive Moderately easy to maintain Moderate MC distribution	[illegible] x Base	[illegible] MC units
Feedforward/ Feedback	Complex to operate Relatively expensive Requires expertise to maintain Requires process information Good MC distribution	[illegible] x Base	[illegible] MC units
Temperature-Drop	Requires moderate expertise to operate Moderate cost Requires moderate expertise to maintain Little process information required Excellent MC distribution	[illegible] x Base	[illegible] MC units

eral multizone batch lumber kilns are being successfully controlled using drying rates and rate-of-change in drying rates for determining when to shut down the kiln and comparing zone-to-zone drying.

Selecting a control scheme

Selection of a dryer control system should be based primarily upon the product quality constraints imposed. However, in some cases, cost and system simplicity dictate the control system. Table 1 compares the four basic dryer control methods. Other methods (for example, model predictive control) have been devised, but these are basically just modifications of the first three.

Simple manual feedback control is still used for some products with very loose MC specifications. However, probably few if any new manual feedback systems are being installed today due to quality and safety constraints.

Where products are dried to reduce shipping costs and later rewet and redried during final processing — for example, wood pulp, agricultural products, and certain chemicals — it is not necessary to have precise MC control in the initial drying step. Therefore, automatic feedback control is sufficient. However, for the final drying phase for an end product such as paper and food products, more sophisticated control is appropriate.

If additional improvement in control is required, feedforward loops may be added in an attempt to correct for disturbances. However, this has a higher cost.

As feedforward/feedback systems become more expensive and complex, use of the temperature-drop system may be appropriate, since it lumps all of the disturbances into the controlled variable ΔT, thus reducing the number of loops, system complexity, and costs.

The temperature-drop system improves batch dryer control by enabling continuous calculation of drying rates, which are more accurate for controlling endpoint MC and for comparing zone-to-zone MC in multizoned batch dryers. Heat-sensitive products, such as pharmaceuticals, foods, starch, and fine chemicals, could profit from the improved control.

FURTHER READING

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