

[54] **BATCH DRYER CONTROL APPARATUS**

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[58] Field of Search **34/28, 30, 31, 45, 48**

[56] **References Cited**

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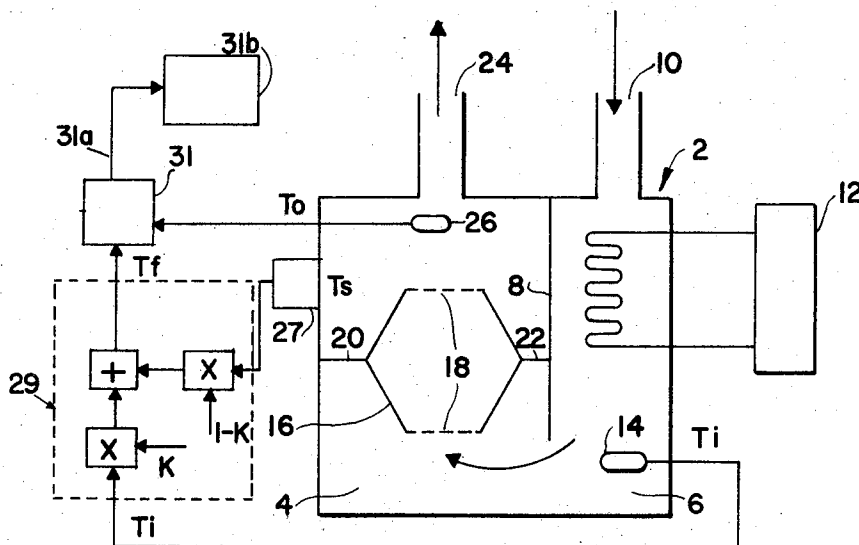
How to Control Product Dryness - pages 47- 51 Instrumentation Technology, Vol. 15, No. 9, Sept. 1968

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[57] **ABSTRACT**

Method and apparatus for controlling the moisture content of a product dried in a batch dryer system wherein the length of the batch drying cycle necessary to result in a predetermined moisture content of the material to be dried is determined by reference to three characteristic temperatures of the process, the temperature of the inlet air, the temperature of the exhaust air and the equilibrium temperature during constant rate evaporation of the solid. The first and third temperature are determined and used to calculate the final value required of the second temperature in order to achieve the proper moisture content of the material. The second temperature is then monitored and the drying cycle is terminated when the final value is reached.

6 Claims, 4 Drawing Figures



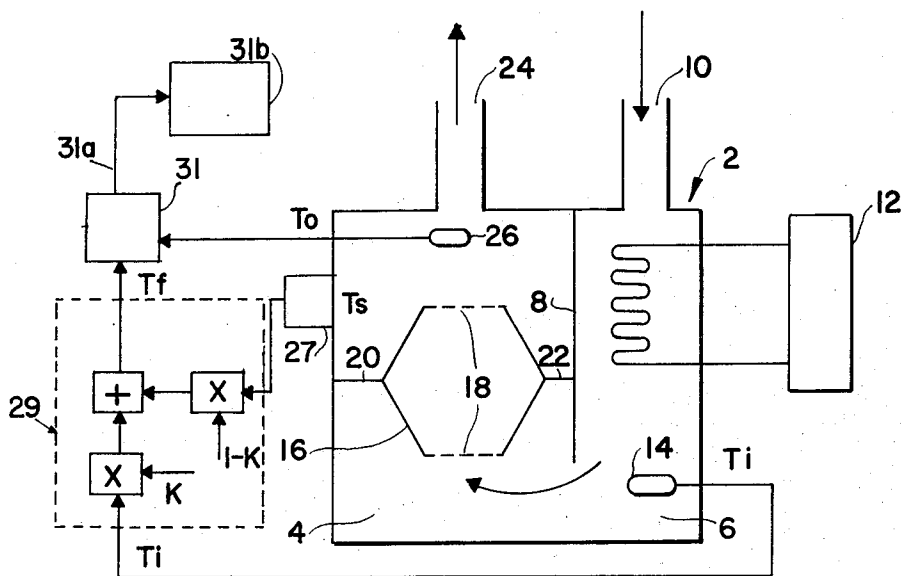


FIG. 1

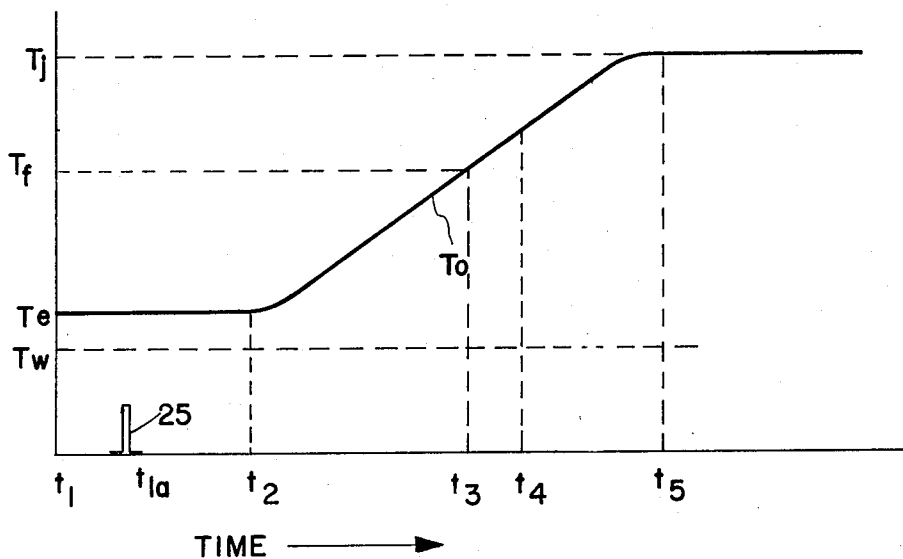


FIG. 2

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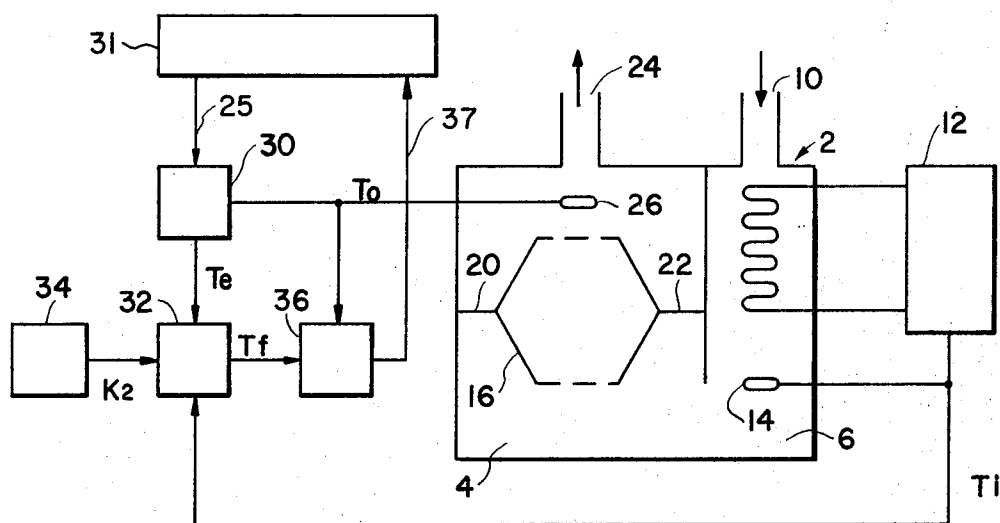


FIG. 3

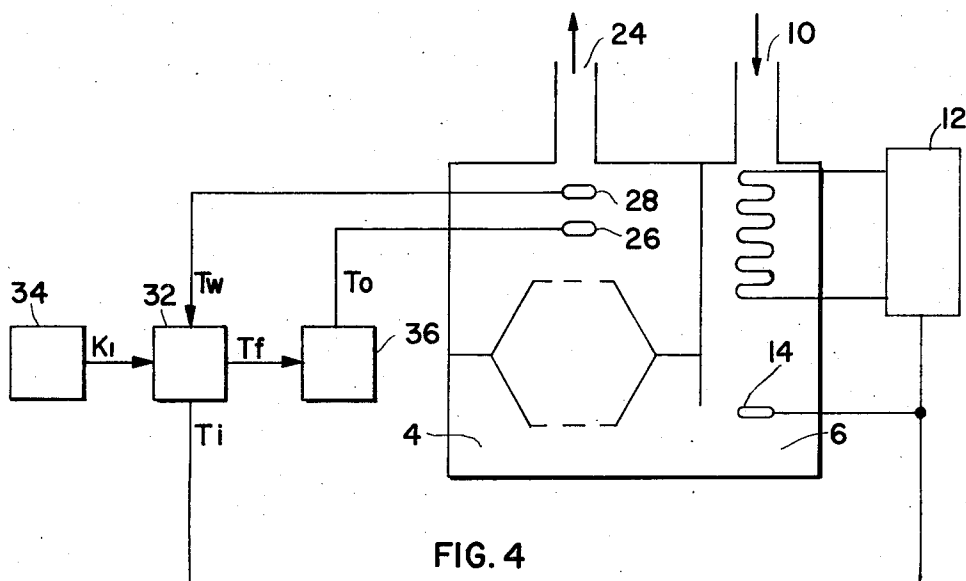


FIG. 4

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BATCH DRYER CONTROL APPARATUS

This invention relates to the automatic control of equipment for drying solid materials in discrete batches. More particularly, this invention relates to control means responsive to certain temperature measurements, and operable to stop the drying operation when the solid material has been dried to a predetermined moisture content.

It is necessary in a number of industrial operations to dry solid materials to a specified degree of moisture content. The solid materials to be dried may, for example, comprise particles, granules, or fragments such as ground wood fiber; ground rock; flakes of plastic such as polyethylene; food products such as grain or fibrous bodies, pharmaceutical products; and others. Typically, the solid material is placed in a chamber and heated air is caused to flow over the material to draw out the moisture. The goal is to stop the drying operation when a desired level of moisture content has been reached.

Although various kinds of equipment for drying solid material have been employed extensively for many years, there has heretofore been very little use of fully automatic controls for operating such equipment. Generally speaking, conventional control techniques, such as feedback or feedforward control, have not been readily applicable to processes for drying solid materials, at least in part because of the difficulty of measuring the moisture content of the solid materials while they are being dried.

Proposals have recently been made for applying automatic control to continuous drying apparatus, as distinct from batch drying apparatus. In that regard, reference may be made to the article entitled "How To Control Product Dryness—Without Measuring It" published at pages 47–51 of Instrumentation Technology, Volume 15, No. 9, dated Sept., 1968. As noted in that article, there is a unique mathematical relationship between three different temperature conditions in a continuous dryer, and as a consequence of that relationship the moisture content of the material can be determined with good accuracy by making certain relatively straight-forward temperature measurements. Thus it is possible to achieve a desired level of dryness through automatic control techniques based upon the measurements of such temperatures.

Batch dryer systems are different in operation from continuous dryers, and the techniques previously developed are not directly applicable to batch operations. Heretofore, the usual approach in operating batch dryer systems has been to maintain the inlet temperature constant, and allow the drying to continue for a predetermined period of time which, by prior experimentation, has been found to provide a desired level of dryness. Although this approach can be successful for a stable and repetitive set of operating conditions, it will be evident that changing conditions necessarily will cause deterioration in the accuracy of control of moisture content. For example, changes in particle size, initial moisture content, or humidity of the inlet air can cause an error in the final dryness of the product.

In accordance with the present invention, a conventional batch dryer is provided with temperature sensors and controls arranged to terminate a drying operation

automatically when a desired level of moisture content has been reached. This automatic control is based upon an established relationship between the final temperature (T_f) of the outlet air, the initial temperature (T_i) of the inlet air, and the equilibrium temperature (T_s) of the solid. The relationship is expressed by the equation:

$$T_f = KT_i + (1-K)T_s$$

K is a constant that depends upon characteristics of the drying equipment, the type of material to be dried, and the specified level of moisture content. After K has been determined, T_i and T_s are measured at the start of a drying cycle, and T_f is computed based upon those measurements. The actual temperature of the exhaust air is continuously measured for comparison with the computed value of T_f , and when the two match, the control equipment automatically terminates the drying cycle.

The equilibrium temperature T_s of the solid is equal to T_w , the wet-bulb temperature of the inlet air and is nearly equal to T_e , the equilibrium temperature of the drying air so that T_s can be determined by measuring either T_e or T_w .

It is a principal object of the present invention to provide improved methods and means for controlling a batch dryer. It is a specific object of the invention to provide methods and means for automatically and repeatably terminating a batch drying cycle at the proper time to achieve a predetermined level of dryness in the product to be dried. It is a further object of the invention to provide such means which functions relatively independently of outside variables, such as moisture content of the air, variation in particle size, shape and moisture.

In the accompanying detailed description, reference will be made to the following drawings, in which:

FIG. 1 is a representation of a batch dryer control system based on the invention;

FIG. 2 is a diagram showing typical variations in temperature in a batch drying cycle;

FIG. 3 shows a batch dryer system incorporating one specific embodiment of the invention; and

FIG. 4 shows a batch dryer system incorporating another specific embodiment of the invention.

Referring now to FIG. 1, there is shown a batch dryer system comprising a main housing 2 divided into a drying chamber 4 and inlet chamber 6 by a partition 8. The drying air is brought in through an air inlet 10, and while passing through inlet chamber 6 is maintained at a constant temperature by a regulated heater 12 of conventional construction. In the inlet chamber 6 there is provided a temperature sensor 14 to measure the dry bulb temperature of the inlet air (T_i).

The heated air passes from inlet chamber 6 into the drying chamber 4 where there is provided a drum 16 containing the material to be dried. This drum is of known construction, and contains numerous openings 18 through which the air can enter and leave. Seals 20 and 22 are provided around the outer edges of the drum to insure that the heated air passes through the interior of the drum before it reaches the exhaust outlet 24.

The dry bulb temperature of the exhaust air (T_o) is measured by a temperature sensor 26. The equilibrium temperature (T_s) of the solid material can be deter-

mined by either of two different measurements (to be described hereinbelow in more detail), and for the purposes of explaining the operation of the equipment shown in FIG. 1, the measurement of T_e is schematically illustrated in the form of a temperature sensor generally indicated by a block 27.

The temperature sensors 14 and 27 produce output signals which are connected to a conventional computation device, generally indicated by a block 29. This device may be of analog or digital type, and is arranged to perform the computation required to obtain the final temperature (T_f) by means of the previously described relationship:

$$T_f = K T_i + (1 - K) T_e.$$

The computing device 29 includes conventional means for multiplying the input temperature value T_i by a constant K , and adding the resulting product to the product of the equilibrium temperature (T_e) and the factor $(1 - K)$. The computing device produces an output signal identifying the computed value of T_f . This output signal is directed to a conventional comparator 31 which receives as its other input a signal corresponding to the output temperature T_o . When the drying operation has proceeded to the point where the output temperature T_o is equal to the computed value T_f , the comparator 31 produces an output signal on its output lead 31a. This output signal is directed to conventional control means, illustrated by block 31b, which thereupon operates to turn off the batch dryer.

Referring now to FIG. 3, a batch drying system is shown wherein the dry bulb inlet temperature from sensor 14 is used to control the heating regulator 12 so as to maintain the inlet temperature constant. This batch dryer includes only a single temperature sensor 26 at the exhaust section of the equipment, and the value of the dry bulb temperature measured by this sensor is used for the dual purposes of computing T_f , and determining when the outlet temperature has reached that computed value.

The computation of T_f is made during the initial stage of the drying operation, because it has been found that the dry bulb outlet temperature of the air during the initial stage corresponds to the equilibrium temperature T_e . More specifically, and referring also to FIG. 2, it will be seen that the outlet temperature T_o passes through three distinct stages. The first is a constant temperature stage, from t_1 to t_2 where the temperature (identified as T_e) is constant because the rate of moisture evaporation from the drying material during this stage is constant. This constant temperature is the equilibrium temperature during constant rate evaporation.

At the second stage (starting at t_2), dry areas on the material make their appearance, so that the rate of evaporation is no longer constant. As further time passes, more and more dry areas appear, and the result is that the outlet temperature T_o increases steadily, in an approximately linear manner.

At some subsequent time, the entire outer surface of the material becomes dry, and the only moisture remaining is in the interior. At that point in the cycle (illustrated by t_4), the drying becomes non-linear, and the continuing increase in the outlet temperature also is non-linear. However, for control purposes, the increase in outlet temperature during this stage can be approxi-

mated as linear, without great loss in control results, and thus the curve in FIG. 2 has been shown as a straight line extending from t_4 to the plateau region at t_5 , where the material is entirely dry.

In the FIG. 3 embodiment, the outlet temperature T_o is measured at the initial stage of the drying operation, and the value of that temperature (T_e) is used as T_e for performing the computation required to determine T_f . Thus the equipment includes a signal memory device, illustrated by a block 30, to which the outlet temperature signal T_o is directed. This memory device, which may be of any known construction including a memory capacitor or other type of element, is activated by a control pulse 25 from a control panel 31. This control pulse is developed at a predetermined time T_{1a} (shown in FIG. 2) after the batch dryer has been turned on, e.g. 3 to 5 minutes after the start time, as by means of any known timing device. When the control pulse is produced, the memory device 30 is momentarily activated, by conventional material switching means, so as to connect the received T_o signal into the memory element where it is stored as T_e .

The stored value of T_e is directed from the memory device 30 to a computing device 32 of conventional construction. This computing device receives two other input signals, one representing the value of the inlet temperature T_i (held constant), and the other representing the constant K referred to in this embodiment as K_2 . K_2 varies from K only as necessary to comply with the difference between T_e and T_i . This constant K is developed by a signal generator 34, manually controlled so as to vary the value of K in accordance with the desired final moisture content. This control normally would be provided with a calibrated scale.

The computing device 32 operates to develop an output signal T_f in accordance with the previously described relationship. This value of T_f is directed as a signal input to the comparator 36, where it is continuously compared with the value of the outlet temperature T_o from the dry bulb sensor 26. When T_o equals T_f , the comparator produces an output signal 37 which is directed to the control panel 31, to shut down the batch dryer.

FIG. 4 shows another embodiment where the exhaust is provided with two temperature sensors. The first sensor 26 furnishes a dry bulb temperature signal T_o , and the second sensor 28 furnishes a wet bulb temperature signal, T_w . As indicated in FIG. 2, the wet bulb temperature T_w is constant and equal to T_e . The relationship between the two temperatures permits T_w to be used as T_e without changing the constant K . The overall relationship can be expressed as

$$T_f = K_1 T_i + (1 - K_1) T_w$$

where K_1 is a new constant, different from K_2 above, and reflecting the difference between T_w and T_e . Since T_w is constant throughout the drying cycle, it is unnecessary to sample the temperature at the start of the cycle, nor to record a sampled value for subsequent computation. Thus, the temperature signal for T_w is connected directly to the computing device 32, together with the signals for K_1 and T_i , so as to generate a signal representing T_f . This signal is used, as before, to set the operating level of the comparator 36 so as to

produce a shut-off signal when the outlet temperature T_o reaches the computed value T_i .

The value of the constant K can be determined experimentally as described hereinbelow. In order to determine the K for a particular level of dryness in a particular batch dryer, the dryer and control system must be configured as in FIG. 3 or FIG. 4. By operating the dryer through one drying cycle with an arbitrary value for K the values of T_e and T_i can be determined. Then, if the approximate temperature at which the desired level of dryness is reached is known, a preliminary value for the constant K can be determined by solution of the following equation which is merely the first herein described equation in form of a ratio

$$K = (T_i - T_e) / (T_i - T_s)$$

The batch drying cycle is then repeated using this value of K . If the desired moisture content of the product is not achieved with this value of K subsequent drying cycles can be run with slightly changed values for K depending on the observed error. If the material is dryer than desired, K should be decreased. If the material contains more moisture than desired, it should be increased. The value of K determined in this way will be proper for the control system used. It will be K_2 for control systems using T_e for T_s , and it will be equal to K_1 for control systems using T_o for T_s .

An alternative method for determining K can be used based on the following observed relationship; in a batch dryer control system of the type herein described the moisture content, M , of the material at the end of a drying cycle is equal to the natural log of $1/K$ multiplied by a constant C , or

$$M = C \ln(1/K)$$

Therefore, at the end of one drying cycle using an arbitrary value of K , if the moisture content is measured C can be determined, because

$$C = M / \ln(1/K)$$

Once C is known the value of K corresponding to any desired value of moisture content can be calculated.

What is claimed is:

1. For use with batch drying equipment including; a drying chamber for containing the material to be dried, and

a drying gas inlet and outlet provided therewith in a manner allowing the drying gas to flow through the chamber, contact said material and outlet therefrom,

control apparatus comprising in combination:

a first temperature sensing means for determining the temperature of the inlet drying gas, a second temperature sensing means for determining the equilibrium temperature during constant rate evaporation of the material, and computing means responsive to the outputs of said temperature sensing means for calculating the temperature of the outlet drying gas related to a particular moisture content of the material,

wherein said second temperature sensing means includes a wet bulb sensor whereby said sensor may also be used to detect the temperature of the outlet drying gas, and

wherein said second temperature sensing means includes a memory means arranged to record the temperature of said outlet drying gas during constant rate evaporation for determining the equilibrium temperature of the solid.

2. For use with batch drying equipment including; a drying chamber for containing the material to be dried, and

a drying gas inlet and outlet provided therewith in a manner allowing the drying gas to flow through the chamber, contact said material and outlet therefrom,

control apparatus comprising in combination:

a first temperature sensing means for determining the temperature of the inlet drying gas, a second temperature sensing means for determining the equilibrium temperature during constant rate evaporation of the material, and computing means responsive to the outputs of said temperature sensing means for calculating the temperature of the outlet drying gas related to a particular moisture content of the material,

wherein said second temperature sensing means includes a wet bulb sensor whereby said sensor may also be used to detect the temperature of the outlet drying gas,

wherein said computing means comprises in combination;

a signal generator for generating a constant signal related to the desired value of moisture content of said material,

computing means responsive to said constant signal and to the outputs of said temperature sensing means operable according to predetermined considerations to provide a resultant temperature signal representative of a final outlet temperature, and

comparator means responsive to said outlet temperature signal and said final outlet temperature signal for generating a control signal to terminate the drying cycle.

3. For use with batch drying equipment including; a drying chamber for containing the material to be dried, and

a drying gas inlet and outlet provided therewith in a manner allowing the drying gas to flow through the chamber, contact said material and outlet therefrom,

control apparatus comprising in combination:

a first temperature sensing means for determining the temperature of the inlet drying gas, a second temperature sensing means for determining the equilibrium temperature during constant rate evaporation of the material, and computing means responsive to the outputs of said temperature sensing means for calculating the temperature of the outlet drying gas related to a particular moisture content of the material,

wherein said second temperature sensing means includes a wet bulb sensor whereby said sensor may also be used to detect the temperature of the outlet drying gas, and

wherein said computing means comprises in combination;

a signal generator for generating a constant signal related to the desired value of moisture content of said material,
 computing means responsive to said constant signal and to the outputs of said temperature sensing means operable according to predetermined considerations to provide a resultant temperature signal representative of a final outlet temperature, and
 comparator means responsive to said outlet temperature signal and said final outlet temperature signal for generating a control signal to terminate the drying cycle,
 wherein said predetermined considerations are in the nature of an equation of the form

$$T_f = K(T_i) + (1-K)T_s$$

where T_f represents said final outlet temperature,
 K represents said constant signal related to the desired value of moisture content,
 T_i represents said inlet temperature, and
 T_s represents said equilibrium temperature of the material.
 4. For use with batch drying equipment including;
 a drying chamber for containing the material to be dried, and
 a drying gas inlet and outlet provided therewith in a manner allowing the drying gas to flow through the chamber, contact said material and outlet therefrom,
 control apparatus comprising in combination:
 a first temperature sensing means for determining the temperature of the inlet drying gas,
 a second temperature sensing means for determining the equilibrium temperature during constant rate evaporation of the material, and
 computing means responsive to the outputs of said temperature sensing means for calculating the temperature of the outlet drying gas related to a particular moisture content of the material,
 wherein said second temperature sensing means includes a web bulb sensor whereby said sensor may also be used to detect the temperature of the outlet drying gas,
 wherein said computing means comprises in combination;
 a signal generator for generating a constant signal related to the desired value of moisture content of said material,
 computing means responsive to said constant signal and to the outputs of said temperature sensing means operable according to predetermined considerations to provide a resultant temperature signal representative of a final outlet temperature,
 comparator means responsive to said outlet temperature signal and said final outlet temperature signal for generating a control signal to terminate the drying cycle,
 wherein said predetermined considerations are in the nature of an equation of the form

$$T_f = K(T_i) + (1-K)T_s$$

where T_f represents said final outlet temperature,
 K represents said constant signal related to the desired value of moisture content,

T_i represents said inlet temperature, and
 T_s represents said equilibrium temperature of the material, and
 wherein said signal generator is manually adjustable and calibrated in terms of desired moisture content of the material.

5. For use with batch drying equipment including; a drying chamber for containing the material to be dried, an air inlet and outlet provided therewith in a manner allowing the air to flow into the chamber, contact the material and flow out therefrom, control apparatus comprising in combination;
 a first dry-bulb temperature sensing element located adjacent said air inlet for sensing the temperature of the air flowing into said chamber,
 a second dry-bulb temperature sensing element located adjacent said air outlet for sensing the temperature of the air flowing out of said chamber,
 memory means responsive to said second temperature element adapted to receive and store the temperature sensed during the constant rate evaporation phase of the drying cycle,
 control means adapted to receive as one input a control signal and terminate the drying cycle upon receipt of said control signal,
 computing means responsive to said first and second temperature elements and said memory means, operable to generate said control signal so as to maintain constant and equal to a predetermined value a ratio of temperature differences, said ratio being the ratio of the difference between the temperature of the outlet air at the end of the cycle and the temperature of the outlet air during constant rate evaporation and the difference between the temperature of the inlet air and the temperature of the outlet air during constant rate evaporation,
 whereby the moisture content of said material when the drying cycle is terminated is directly related to said predetermined value of said ratio, and
 whereby said drying cycle is controlled so as to repeatedly and accurately dry the material to the desired moisture content, and
 whereby said desired moisture content is determined by the choice of said value for said ratio.

6. For use with batch drying equipment including;
 a drying chamber for containing the material to be dried, and
 a drying gas inlet and outlet provided therewith in a manner allowing the drying gas to flow through the chamber, contact said material and outlet therefrom,
 control apparatus comprising in combination:
 a first temperature sensing means for determining the temperature of the inlet drying gas,
 a second temperature sensing means for determining the temperature of the inlet drying gas and the equilibrium temperature of the material, and
 computing means responsive to the outputs of said temperature sensing means operable according to predetermined considerations to provide a resultant indication representative of the moisture content of said material,
 wherein said computing means comprises in combination;

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a signal generator for generating a constant signal related to the desired value of moisture content of said material,
 computing means responsive to said constant signal and to the outputs of said temperature sensing means operable according to predetermined considerations to provide a resultant tem-

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perature signal representative of a final outlet temperature, and
 comparator means responsive to said outlet temperature signal and said final outlet temperature signal for generating a control signal to terminate the drying cycle.

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