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Fowler et al.

[11] **3,905,123**

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[54] **METHOD AND APPARATUS FOR CONTROLLING A TOBACCO DRYER**

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[52] **U.S. Cl.** **34/31;** 34/46; 131/135
[51] **Int. Cl.**[2] **F26B 3/04;** A24B 9/00
[58] **Field of Search** 34/29, 30, 31, 33, 34, 34/48, 54, 22, 26, 28, 32, 45; 131/135

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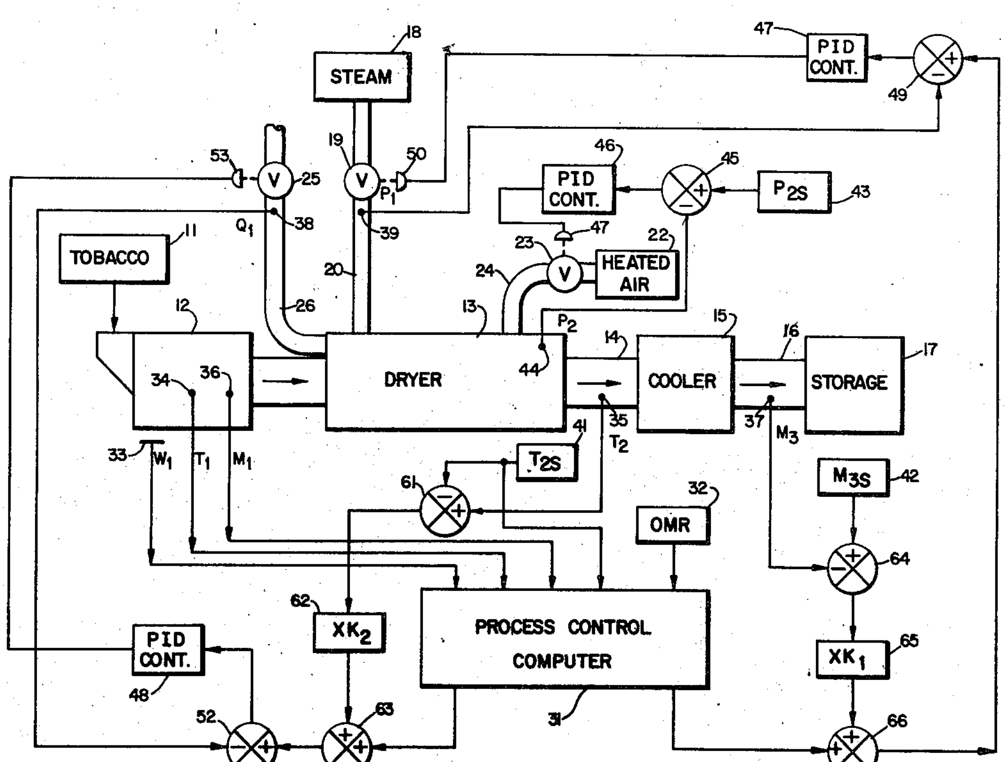
[57] **ABSTRACT**

A controller for a tobacco dryer system including a drum type dryer and a cooler includes transducers for deriving signals indicative of weight and moisture of tobacco entering the dryer system. In response to the weight and moisture of the entering tobacco, there is derived a first signal indicative of dryer duty to achieve a desired moisture for tabacco exiting the system. A second signal indicative of the dry weight of the processed tobacco is derived in response to the input tobacco moisture and weight. The temperature differential of the tobacco entering and exiting the drum is also derived. The moisture, weight and temperature differential indicating signals are combined to derive a signal indicative of the heat added by the dryer to the tobacco passing through the dryer. Set point signals for the flow rate of drying gas passing through the dryer and the temperature of the dryer walls are derived in response to the signals indicative of dryer duty, bone dry weight of tobacco, and heat added by the dryer to the tobacco.

23 Claims, 2 Drawing Figures



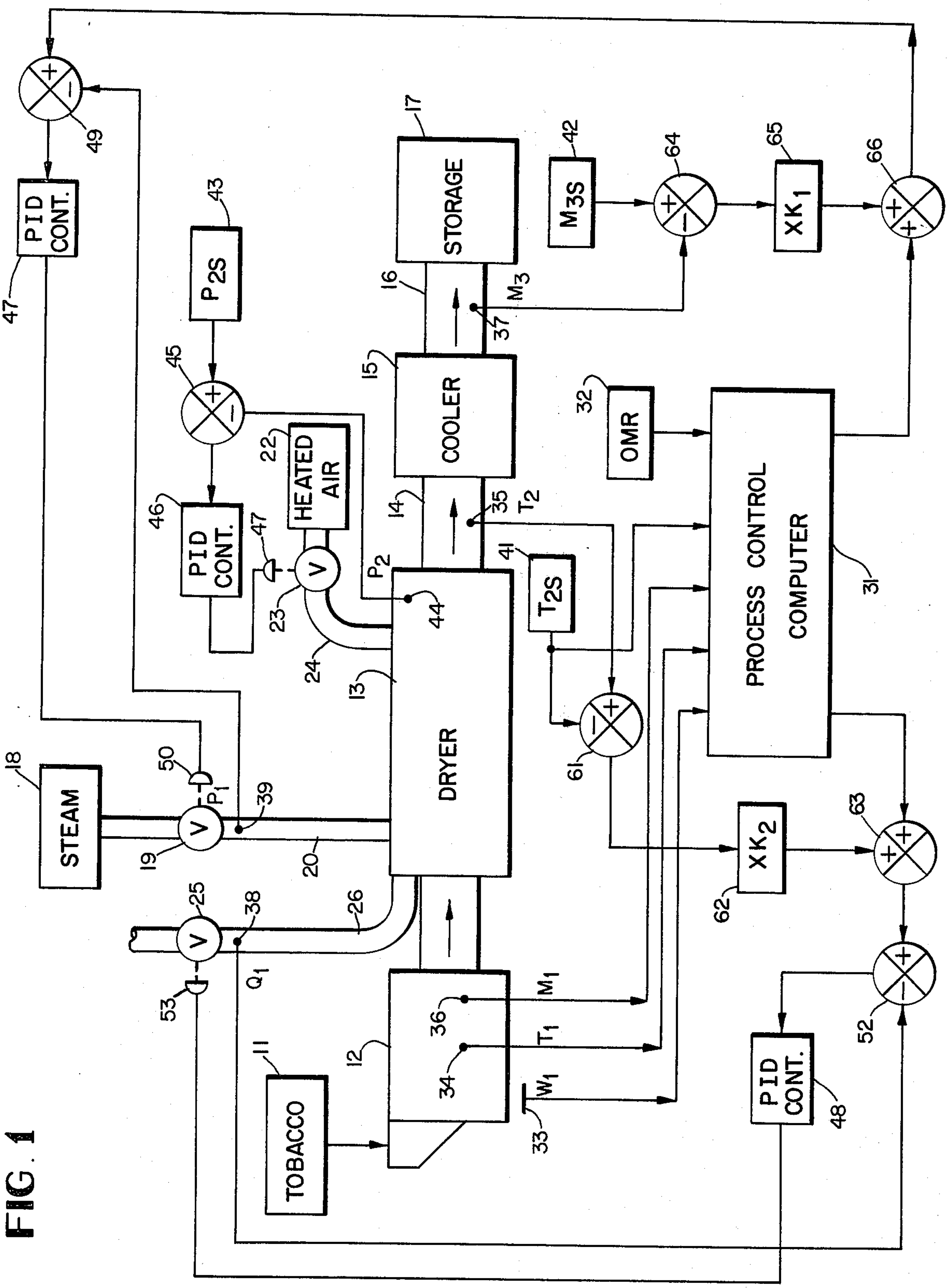

STORAGE
COOLER
DRYER
HEATED AIR
STEAM
TOBACCO
PROCESS CONTROL COMPUTER
OMR
PID CONT.
PID CONT.
PID CONT.
P_{2S}
T_{2S}
M_{3S}
XK_1
XK_2
V
V
V
P_1
P_2
Q_1
M_1
T_1
W_1
T_2
M_3

FIG. 1

FIG. 2

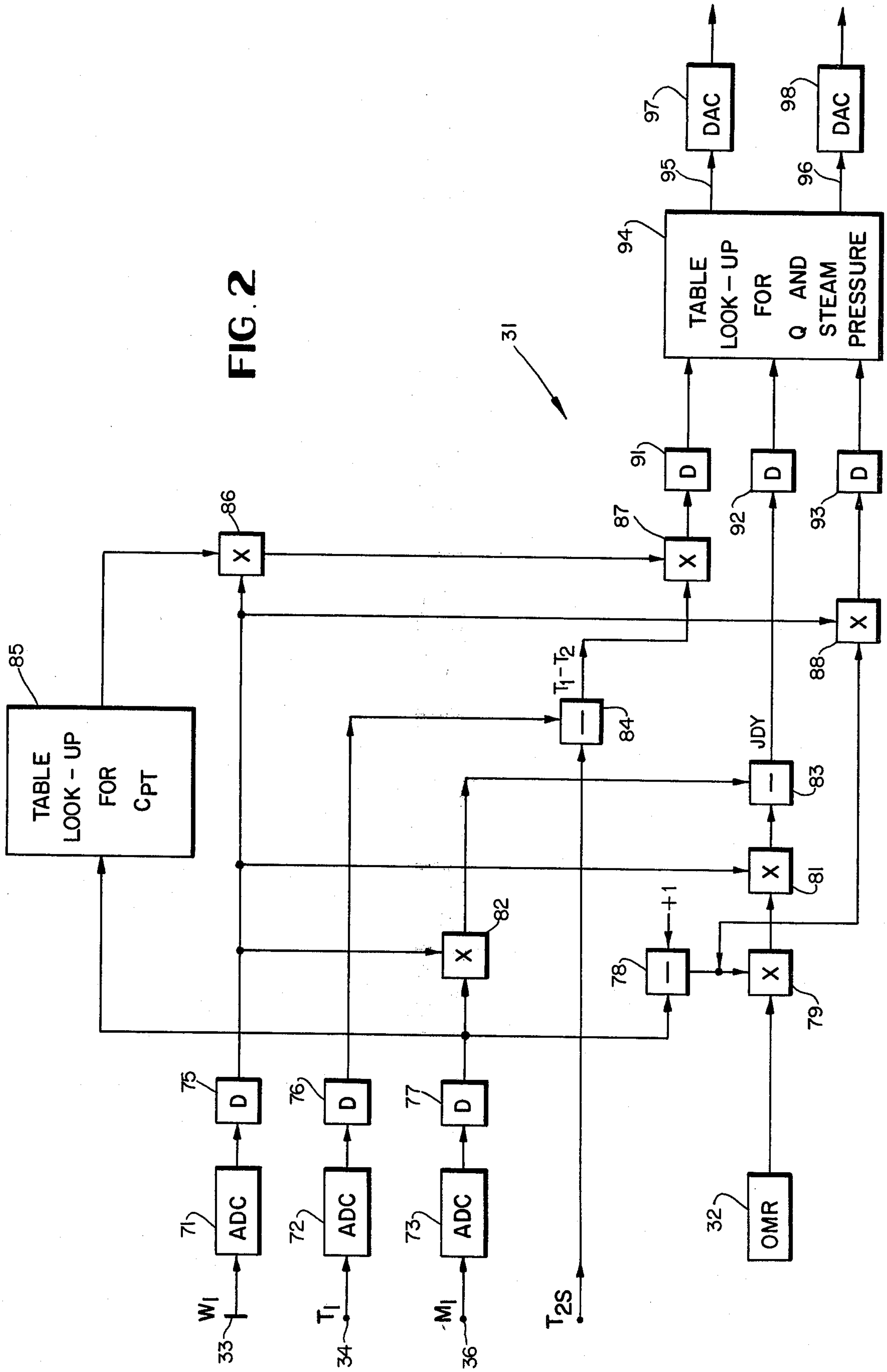


TABLE LOOK - UP FOR C_{PT}
TABLE LOOK – UP FOR Q AND STEAM PRESSURE
ADC
D
X
DAC
OMR
W_1
T_1
M_1
T_{2S}
T_1-T_2
JDY
+1
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METHOD AND APPARATUS FOR CONTROLLING A TOBACCO DRYER

FIELD OF THE INVENTION

The present invention relates generally to controllers for tobacco dryers and more particularly to a tobacco dryer controller wherein flow rate of a gas passing through the dryer and the temperature of heat exchange surfaces of the dryer are concomitantly controlled.

BACKGROUND OF THE INVENTION

In the past, the philosophy for tobacco dryer controllers has generally been based on attempting to obtain a predetermined moisture for tobacco exiting the dryer, with little consideration being given to the quality of cigarettes ultimately manufactured, nor of the "filling power" of tobacco in the cigarettes. Characteristics of cigarettes which are affected to a large extent by the dryer are firmness and the existence of loose ends. Firmness and loose ends are key quality parameters which influence the consumer acceptance of finished cigarettes. Also, from an economic standpoint, the cigarette manufacturer is interested in producing a tobacco having a characteristic referred to as maximum filling power. We have found that controlling only moisture of tobacco exiting a tobacco dryer does not necessarily provide consistent and desired control of the aforementioned characteristics of cigarette firmness, loose ends, and filling power.

BRIEF DESCRIPTION OF THE INVENTION

In accordance with the invention, an improvement in these and other cigarette characteristics is attained by controlling the flow rate of a gas flowing through a drum type dryer concomitantly with the temperature of heat exchange or heat transfer surfaces of the dryer. Generally, the gas flow can be either countercurrent with the direction of tobacco movement or in the same direction as the tobacco movement through the drum. The concomittant control can be used to produce tobacco having certain characteristics shown from past experience to achieve the aforementioned characteristics or to produce tobacco having predetermined temperature and moisture.

The philosophy to produce tobacco having the aforementioned desirable characteristics is based on our finding that variations along the dryer length have a substantial effect on the firmness, loose ends and filling power of tobacco in a cigarette. In a tobacco dryer including a rotating drum, variations in the parameters of tobacco moisture, temperature, and drying rate, as well as air humidity, within the drum as a function of position along the length of the drum have an important effect on the three variables of filling power, firmness, and loose ends. Theoretically, from our investigations, it would appear that the most desirable technique for controlling the variations of these parameters is to provide different controllers along the length of the dryer for the various parameters. However, this is not usually practical because all or virtually all existing drum type dryers have only the ability to control each of the parameters at a single discrete location in the dryer or outside of the dryer. Therefore, from a practical standpoint, the variations of air humidity, tobacco moisture, tobacco temperature, and tobacco drying rate within the dryer can only be controlled on a discrete basis for individual controllers, rather than on a distributed basis throughout the dryer.

We have found that the variations of tobacco drying rate, tobacco moisture, and tobacco temperature, as well as air humidity, within the dryer as a function of dryer longitudinal position (frequently referred to as profiles), can be optimally adjusted to achieve the aforementioned desired characteristics by concomitant control of the temperature of dryer heat exchange surfaces, e.g., the dryer wall, and flow rate of gaseous, drying fluid current flowing through the dryer in a direction opposite to the movement of tobacco through the dryer. While the countercurrent gas flow rate and dryer wall temperature are relatively fixed quantities as a function of dryer length, they do have significant effects on the amplitude and distribution as a function of dryer length of the aforementioned variations.

We have found that the temperature of the hot gaseous usually usually, air, flowing through the dryer is not nearly as significant to achieve the aforementioned desirable characteristics as the flow rate of the fluid. In particular, as air flow increases, the humidity of air within the dryer has a tendency to decrease. For low flow rates (e.g., 800 feet^3/minute) of the hot air, the air humidity in the downstream portion of the dryer, relative to tobacco movement, is considerably less than the peak air humidity which occurs at a relatively forward location within the dryer and is much greater than the relative air humidity for high air flow rates, (e.g., 2000 feet^3/minute). Also, at the high air flow rate, the amount of humidification in the forward end of the dryer is relatively minor, while for low air flow rates, the humidification effect close to the dryer inlet becomes a significant effect. For tobacco entering the dryer at a particular temperature, the tobacco temperature versus position trajectory throughout the dryer length is also dependent upon flow rate, being represented by a family of constant air flow curves having a common temperature value at the dryer inlet. The curves for the low air flow rates have higher temperature values along the length of the drum than the curves for the high air flow rates, whereby the temperature of tobacco exiting the dryer for low air flow rates is greater than the temperature of tobacco existing the dryer for the high air flow rates, assuming the tobacco entering the dryer for the two flow rates has the same temperature.

In a preferred embodiment, the controller relies upon the noted variations of tobacco moisture, drying rate, and temperature, as well as air humidity, to achieve maximum filling power, while obtaining desired firmness and loose ends. The dryer temperature and air current flow rate are controlled by calculating three parameters, viz: dryer duty, the change in heat energy of the tobacco due to the tobacco passing through the dryer drum, and the bone dry weight of the tobacco passing through the dryer. Dryer duty equals the dryer heat required to evaporate water from the tobacco to achieve a predetermined mositure for the tobacco exiting from the dryer system. The dryer duty is calculated in response to measurements of the weight and percentage of moisture of the tobacco entering the dryer, as well as a predetermined set point value for the ratio of water to dry tobacco exiting the system.

The change in tobacco heat energy, frequently referred to as sensible heat, is calculated by determining the temperature difference of tobacco entering and exiting the dryer drum, as well as the weight of the inlet tobacco. The temperature difference is multiplied by the weight of the inlet tobacco and a quantity indicative of the specific heat of the tobacco supplied to the dryer. In certain instances, the specific heat of the tobacco is a predetermined quantity, provided the moisture of the inlet tobacco remains relatively constant. However, if the moisture of the inlet tobacco varies over a relatively wide range, the specific heat of the moisture has a corresponding variation, necessitating an alteration of the tobacco specific heat as a function of the amount of moisture in tobacco being fed to the dryer.

The bone dry weight of the tobacco being processed is the weight of the tobacco, assuming zero moisture. Tobacco bone dry weight is determined by multiplying the measured weight of the tobacco processed by a quantity derived by subtracting the moisture fraction measurement from unity.

The signals indicative of the dryer duty, sensible heat, and tobacco bone dry weight are combined to derive set point values for flow rate and dryer wall temperature to achieve the desired cigarette qualities. One technique which may be utilized for deriving the set point values involves a table look-up based upon prior data which was found to produce optimum results for the cigarette parameters of filling power, loose ends, and firmness. Hence, prior to activating the controller of the present invention, it is necessary to take several series of measurements on each particular dryer. From these measurements, the dryer temperature and air flow rates which produce the desired cigarette characteristics are derived as functions of the measured parameters.

In accordance with another aspect of the invention, the concomitant control of the dryer and gas flow rate in either direction provides improved results over prior art techniques by maintaining the temperature and moisture of tobacco exiting the dryer at predetermined set points. By maintaining the temperature and moisture of tobacco exiting the dryer at the set point values, the present invention achieves more desirable downstream tobacco processing, e.g., cooling, flavoring, and bulk storage.

It is, accordingly, an object of the present invention to provide a new and improved tobacco dryer controller.

A further object of the invention is to provide a new and improved tobacco drum type dryer controller wherein cigarettes having improved characteristics can be produced.

An additional object of the invention is to provide a new and improved tobacco dryer controller wherein the flow rate of a gas stream and the temperature of the dryer are concomitantly controlled.

A further object of the invention is to provide a tobacco dryer in which the temperature and moisture of tobacco exiting a dryer are controlled to set point values.

Another object of the invention is to provide a new and improved tobacco dryer controller wherein parameters within the interior of a tobacco dryer are effectively controlled as a function of the length of the dryer, while utilizing discrete controllers, rather than distributed controllers along the dryer length.

Another object of the invention is to provide a new and improved tobacco dryer controller for enabling the production of cigarettes having maximum filling power, desired firmness, and a relatively small number of loose ends.

The above and still further objects, features, and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is an overall schematic block diagram of a preferred embodiment of the present invention; and

FIG. 2 is a block diagram of one embodiment of a control computer illustrated in the block diagram of FIG. 1.

DETAILED DESCRIPTION OF THE DRAWING

Reference is now made to FIG. 1 of the drawing wherein there is illustrated a source **11** of relatively moist tobacco, typically having a moisture of 20 percent by weight, which is fed via a conveying system, including belt weigher **12**, to a controlled dryer **13**. Dryer **13** is a type wherein tobacco flows into and out of it, and the tobacco flows through the dryer so that the tobacco is resident in the dryer for a substantial time period. During normal operation, tobacco continuously flows through dryer **13** in the direction indicated from left to right on the drawing. Tobacco flowing from dryer **13** is conveyed by conveyor **14** to cooler **15**, thence on conveyor **16** to storage bin **17**.

Typically, dryer **13** is of the rotary drum type, wherein the drum rotates about a generally horizontally disposed axis and is provided with heat transfer or exchange surfaces, such as axially oriented drying paddles attached to the dryer shell. The paddles are provided with pipes through which steam is passed whereby tobacco flowing across the paddles is heated by the paddles as the tobacco circulates along the length of the dryer. Dryer **13** may also be provided with added heat exchange surfaces, e.g., steam pipes on its interior walls. Dryer steam is supplied to the steam pipes of dryer **13** from steam source **18** via valve **19** and conduit **20**, whereby all of the steam pipes througout the length of dryer **13** are responsive to steam being fed into the dryer at a single point from a single source. Variations in the opening of valve **19** affect the temperature of the walls of dryer **13**, thereby directly influencing the extent of tobacco drying in dryer **13**.

The extent of tobacco drying in dryer **13** is also controlled by the flow of a relatively dry source of heated gaseous fluid, usually air, which in the preferred embodiment flows countercurrent in the dryer relative to the movement of tobacco in the dryer. To this end, a source **22** of heated air is connected in proximity to the right end of dryer **13** via valve **23** and conduit **24**. Valve **23** is provided to maintain a slight, negative static pressure on the right side of dryer **13** to prevent dust in the tobacco exiting dryer **13** from being distributed into the remainder of the system. The flow rate of air from source **22** through the length of dryer **13** is controlled by valve **25** which is connected in conduit **26** to the left end of the dryer, where tobacco from belt weigher **12** initially enters the dryer. By varying the flow rate of air from source **22** through dryer **13**, the humidity of the air in the dryer is controlled, as are the temperature, moisture, and drying rate of tobacco flowing through the dryer. Variations in the flow rate of air from source 22 through dryer 13 have a considerable effect on the final values of the four parameters, as well as the variations of these parameters along the length of the dryer, as described supra.

To provide controls for the positions of valves 19 and 25, and thereby for the wall temperature of dryer 13 and the flow rate of air from source 22, transducers are provided for monitoring the weight, temperature, and weight fraction moisture (W_1, T_1, and M_1 respectively) of tobacco entering the dryer, as well as for monitoring the temperature (T_2) of tobacco exiting dryer 13. Signals indicative of the values of W_1, T_1, and M_1, are combined in process control computer 31 with first and second set point signals, OMR and T_{2s}, respectively derived from operator controlled input sources 32 and 41 which are indicative of set points of a desired fraction of moisture weight in the total weight of dry tobacco exiting the dryer system on conveyor 16 from cooler 15 and the temperature of tobacco exiting the dryer. Process control computer 31 responds to the five input signals supplied thereto to derive set point control signals for the settings of valves 19 and 25. Control for the positions of valves 19 and 25 is also provided in response to signals indicative of the moisture (M_3) of tobacco exiting cooler 15 on conveyor 16, the pressure (P_1) of steam in conduit 20 that feeds 13, and the flow rate (Q_1) of heated air flowing from source 22 through dryer 13.

The various signals indicative of the tobacco properties and the steam pressure and air flow rate are derived by appropriate transducers. In particular, the weight of tobacco on beltweigher 12 is derived with beltweigher transducer 33 while the temperature of the tobacco entering and exiting dryer drum 13 is derived by temperature-sensing, thermometer type transducers 34 and 35 which are respectively located on beltweigher 12 and conveyor 14. The moisture of tobacco entering dryer 13 and exiting cooler 15 is monitored by moisture monitoring transducers 36 and 37, which are respectively positioned to be responsive to the moisture of tobacco on conveyors 12 and 16. Moisture tranducers 36 and 37 can be of any well known type, such as infra-red photoelectric transducers or dielectric transducers, and derive output signals indicative of the weight percent moisture of the tobacco. The flow rate of air from source 22 flowing through dryer 13 is monitored by providing a flow meter 38 in conduit 26, while the pressure of steam in conduit 20 is provided by mounting a steam transducer 39 on conduit 20. Transducers 38 and 39 are provided to establish negative feedback control loops for maintaining the flow rate of air in dryer 13 and the pressure in conduit 20 at levels which control the dryer so that the tobacco exiting the dryer has a predetermined set point temperature, T_{2s}, and the tobacco exiting cooler 15 has a predetermined moisture, M_{3s}. The values of T_{2s} and M_{3s} are derived from operator controlled input sources 41 and 42, respectively. The temperature of tobacco exiting the dryer is maintained sufficiently close to the set point value by a feedback control loop responsive to source 41 and transducer 35 that the set point value can be supplied to computer 31 to indicate the temperature of the tobacco exiting drum 13. Supplying the temperature and OMR set points to computer 31 has the advantage of providing predictive type signals for the computer to process.

One further local feedback loop is provided to maintain the static pressure at the right side of dryer 13 at a predetermined set point value, P_{2s}, as derived from operator control input source 43. The local loop for control of the static pressure at the right side of dryer 13 is provided by including a pressure transducer 44 in proximity of the right wall of the dryer, downstream of the entrance point for steam in conduit 24 into dryer 13. The pressure indicating signal derived from transducer 44 is supplied to a comparison network comprising subtraction node 45, having a positive input responsive to the P_{2s} signal derived from source 43 and a negative input responsive to transducer 44. Subtraction node 45 derives an error signal which is supplied to a proportional-integral-differential (PID) controller 46 that derives an output signal for controlling actuator 47 of valve 23.

Valves 19 and 25 are also respectively provided with local PID controllers 47 and 48. Controller 47 is driven by an error signal derived from a comparison network comprising subtraction node 49. Node 49 has a positive input terminal responsive to a signal indicative of a set point for the steam pressure of valve 19, and a negative input responsive to a signal indicative to the measured steam pressure in line 20, as derived from transducer 39. Controller 47 derives an output signal which is fed to valve actuator 50 that drives valve 19 to maintain the pressure in conduit 20 at a level commensurate with the value supplied to the positive input of node 49. Similarly, controller 48 is responsive to an error signal indicative of the difference between the set point value for the air flow rate of dryer 13, as supplied to a positive input terminal of subtraction node 52, and a measure of the actual flow rate in conduit 26, as derived from transducer 38 and supplied to a negative input terminal of node 52. Controller 48 responds to the error signal supplied to it to drive valve actuator 53 for valve 25.

Broadly, process control computer 31 responds to the W_1, T_1, and M_1 signals derived from transducers 33, 34, and 36 as well as the OMR and T_{2s} signals derived from sources 32 and 41, to compute signals indicative of: (1) dryer duty, (2) amount of heat energy change induced by dryer drum 13 in the tobacco flowing through the drum, and the bone dry basis weight of tobacco passing through the drum. The dryer duty (JDY) is calculated as a function of W_1, M_1, and T_1 in accordance with:

$$JDY = M_1W - OMR\,(1 - M_1)W_1 \qquad (1)$$

The amount of heat energy change (SH) induced by the dryer 13 is the tobacco flowing through the dryer is calculated, generally, as a function of W_1, M_1, T_1, and T_{2s} in accordance with:

$$SH = W_1C_{PT}(T_{2s} - T_1) \qquad (2)$$

where C_{PT} = specific heat of tobacco entering the dryer.

In Equation 2, the value of C_{PT} is generally a function of the amount of moisture in the tobacco entering the dryer. Hence, in the general situation, computer 31 includes a table look-up relating moisture of tobacco entering the dryer to tobacco specific heat. In certain instances, however, wherein tobacco moisture entering dryer drum 13 is maintained relatively constant (generally less than a three percent variation), the tobacco specific heat is relatively constant, and the moisture variation need not enter into the determination of the specific heat of tobacco, whereby the specific heat can be considered as a predetermined constant. Bone dry weight (BD) of tobacco flowing through dryer **13** is calculated in accordance with:

$$BD = (1 - M_1)W_1 \quad (3)$$

Computer **31** responds to the values calculated by Equations (1), (2), and (3) to derive set point signals for the flow rate of counter current heated air in dryer **13** and the temperature of the dryer wall. To determine the set point signals for air flow rate and dryer temperature, computer **31** may include a table look-up signal storage device. The table look-up is established by ascertaining, from measurements of the drying system including dryer drum **13** and cooler **15**, the values of air flow rate and dryer temperature which optimize maker performance to achieve the best cigarettes as a function of filling factor, loose ends and firmness for each particular set of values for the computed variables of Equations (1), (2), and (3). In the alternative, computer **31** determines optimum values for air flow rate and dryer temperature in response to model equations for dryer **13**.

The dryer temperature and dryer air flow set point signals derived from computer **31** are modified by error signals between measured values for the temperature and moisture of tobacco exiting dryer **13** and cooler **15**. To these ends, the T_2 temperature signal derived from transducer **35** is compared with the T_{2s} set point signal derived from source **41**. The comparison is performed in subtraction node **61**, having a negative input responsive to the signal derived from transducer **35** and a positive input responsive to the signal derived from source **41**. Node **61** derives an error output signal which is multiplied in multiplier **62** by a predetermined gain factor (K_2) relating temperature error of tobacco exiting dryer **13** to air flow rate. The output signal of multiplier **62** is linearly combined in adder **63** with the air flow rate set point signal derived from process control computer **31**. Thereby, adding node **63** derives a modified air flow rate set point signal which is supplied to the positive input of difference node **52**. Similarly, a comparison of the measured and set point values for M_3 is derived by difference node **64**. Node **64** includes a positive input terminal responsive to source **42** and a negative input terminal responsive to transducer **37** for deriving an error signal which is modified by a predetermined, fixed gain factor (K_3) in multiplier **65**. The gain factor K_3 represents the amount by which the steam pressure is related to dryer output moisture error. The output signal of multiplier **65** is linearly combined in adding network **66** with a temperature indicating set point signal for dryer **13**, as derived from process control computer **31**. The resultant sum derived from node **66** is applied as a positive input to node **49** which ultimately drives actuator **50**, as described supra.

Process control computer **31** may be a general purpose, properly programmed digital computer, an analog computer, or a special purpose digital computer. For ease of presentation, the computer is illustrated in FIG. **2** as being a special purpose digital computer having the usual analog to digital converters, digital to analog converters, table look-up memory, and arithmetic units including multipliers, adders, and subtracters. The signals derived from transducers **33, 34** and **36** are usually of the analog type, being voltages or currents proportional in magnitude to the measured variable. The analog signals derived from transducers **33, 34** and **36** are converted into digital signals which can be processed by computer **31**, with such conversions being respectively performed by analog to digital converters **71, 72** and **74**. Because of the transport lag from the position of transducers **33, 34,** and **36,** prior to entry of the tobacco into dryer **13**, to a selected reference point adjacent the dryer inlet, it is necessary to time-synchronize the signals derived from the various transducers so that the outputs of the several transducers represent the same segment of tobacco. To this end, the output signals of converters **71, 72** and **74** are respectively applied to delay elements **75–77** which respectively introduce signal delay times equal to the transport lag times from the transducers **33, 34,** and **36** to the reference point. There is no need to delay the set point input signals to computer **31** since they do not vary and are therefore the same for a particular set point value for all segments of the tobacco moving past the reference point.

The dryer duty is found by combining the output signals of delay elements **75** and **77** with the operator set point signal (OMR) derived from digital source signal **32**. The signal derived from source **32** is indicated as being directly proportional to the set point for the weight ratio of water in the tobacco to the bone dry tobacco exiting the drying system, at the exit of cooler **15**,

$$OMR = \frac{M_{3s}}{1 - M_{3s}} \quad (4)$$

In the alternative, the OMR ratio could be computed from an entry by the operator for the moisture set point (M_{3s}). In such an instance, the value of M_{3s} is converted by computer **31** into a signal indicative of the OMR ratio in accordance with Equation (4).

The second term on the right side of Equation (1), OMR $(1 - M_1)W_1$ indicative of the desired moisture weight of tobacco exiting cooler **15**, is computed by subtracting the M_1 indicating output signal of delay element **77** from a predetermined constant having a magnitude representing +1, in digital subtracter matrix **78**. The output signal of matrix **78**, a digital signal representing $(1 - M_1)$, is multiplied in multiplying matrix **79** by the OMR ratio derived from source **32**. The output signal of matrix **79**, commensurate with OMR $(1 - M_1)$, is multiplied in multiplier **81** by the output signal of delay element **75**, indicative of W_1. Multiplier **81** thereby derives an output signal representing +OMR$(1 - M_1)W_1$, a term commensurate with the amount of moisture in the tobacco exiting cooler **15**. The output signal of multiplier **81** is linearly combined with a signal representing the weight of water in tobacco entering dryer **13**, (W_1M_1) a term derived by multiplying in multiplier **81** the W_1 output of delay element **75** by the M_1 output of delay element **77**. The output signals of multipliers **81** and **82** are combined in subtraction matrix **83**, which derives an output signal representing dryer duty in accordance with Equation (1).

To determine the change in heat energy induced by dryer **13** in the tobacco flowing through the dryer in accordance with Equation (2), the temperature difference of tobacco entering and exiting dryer **13** is determined by subtracting the T_1 output of delay element **76** from the T_{2s} set point in subtracter matrix **84**, which derives a digital output signal commensurate with $T_{2s} - T_1$. The specific heat of tobacco for the particular moisture content, M_1, is determined by supplying the output signal of delay element **77** to a table look-up **85** which relates moisture percentage to specific heat. Table look-up **85** may be any well known type and generally includes a circuit for determining in which one of a number of range values the magnitude of M_1 lies. The magnitude of M_1 is fed to a memory which may be any of the well known types, such as a magnetic core or semi-conductor matrix, which derives a digital output signal representing the specific heat of the tobacco for the particular moisture magnitude. The specific heat value C_{PT} derived from table look-up **85** is supplied to multiplying matrix **86** which is also responsive to the W_1 indicating output signal of delay element **75.** The product signal (W_1C_{PT}) thereby derived from multiplier matrix **86** represents the amount of energy required to raise the mass of input tobacco one degree in temperature. If it is expected that moisture of tobacco entering dryer **13** is relatively constant (e.g., it does not deviate by more than three percent from a predetermined value), table look-up **85** may be replaced with a predetermined constant indicative of the specific heat of tobacco for the particular moisture value. To determine the sensible heat actually removed by the dryer **13** from the mass of tobacco fed to the dryer, the product signal derived from multiplier matrix **86** is multiplied in matrix **87** by the temperature difference signal derived from subtracter matrix **84.** The output signal of multiplier **87** is thereby indicative of sensible heat as indicated by Equation (2), and represents the heat energy supplied by dryer **13** to the mass of tobacco entering the dryer; a negative value indicates the heat energy removed by the dryer from the tobacco mass.

To determine the bone dry weight of the tobacco flowing through dryer **13** in accordance with Equation (3), the $(1-M_1)$ output signal of subtracter matrix **78** is multiplied in multiplier matrix **88** by the W_1 output signal of delay element **75.** The output signal of multiplier matrix **88** is thereby commensurate with $W_1(1-M_1)$ to provide an indication of the weight of tobacco flowing through the dryer, sans moisture.

The signals indicative of dryer duty, sensible heat and bone dry weight are derived for a segment of tobacco entering dryer drum **13** and therefore are feed forward signals to control the performance of the dryer as the segment moves through the drum. However, the residence time of tobacco in drum **13** is relatively long compared to the periodicity of the derived signals; typically the residence time is about five minutes and the signals are derived about once every ten seconds. Hence, there is a significant transport lag between the time the tobacco segment enters the drum and when it gets to the interior of the drum. To compensate for this lag, the signals indicative of dryer duty, sensible heat, and bone dry weight are respectively filtered and delayed in filter and delay elements **91, 92,** and **93,** each of which preferably has a different characteristic dependent on dynamic characteristics of dryer drum **13** and its associated components.

The output signals of delay elements **91–93** are fed into a three-dimensional table look-up **94** having a pair of output leads **95** and **96** on which are derived digital signals commensurate with set point values for air flow rate and dryer temperature. The signals on leads **95** and **96** are derived by table look-up **94** for the entire interval between successive readouts of the values of delay elements **91–93.** Table look-up **94** may be of any well known type and includes circuitry for dividing each of its three input signals into differing ranges and a matrix responsive to the range indications for locating intersection points for the magnitudes of dryer duty, sensible heat, and bone dry weight. In response to each intersection point being located, the table look-up derives a pair of output signals, one for dryer temperature and the other for air flow rate.

The air flow and temperature set point signals derived on leads **95** and **96** are respectively supplied to digital to analog converters **97** and **98,** which derive constant analog signal magnitudes indicative of the set points over the entire averaging period of averaging circuits **91–93.** The output signals of converters **97** and **98** are respectively supplied to summing nodes **63** and **66** to control the average dryer air flow rate and temperature during the next averaging period of averaging circuits **91–93.**

While the embodiment of FIGS. **1** and **2** provides optimum results, improved results in the operation of downstream processors can be attained by eliminating process control computer **31** while controlling steam pressure concomitantly with flow rate to achieve set point values for tobacco exiting drum **13** and desired moisture for tobacco exiting cooler **15** or dryer **13.** To these ends, the temperature and moisture set point values derived from sources **41** and **42,** after being compared in difference nodes **61** and **64** with the measured values derived from transducers **35** and **37,** are applied with appropriate gain directly as control signals to PID controllers **48** and **47,** without being combined with computed set point signals. In the alternative, if it is desired to maintain the moisture of tobacco exiting drum **13** at a value that is slightly more precise than can be attained with a moisture transducer on conveyor **16,** moisture transducers **37** is positioned to be responsive to tobacco on conveyor **14.** If the less than optimum system is employed, the flow of air from source **22** can be either co-current or countercurrent of tobacco through drum **13.**

While several embodiments have been described and one specific embodiment of the invention has been illustrated, it will be clear that variations in the details of the embodiment specifically illustrated and described may be made without departing from the true spirit and scope of the invention as defined in the appended claims. For example, the tobacco fed to dryer **13** can be derived from sources of cut rolled stems and laminae, as described in the co-pending commonly assigned application Ser. No. 280,115, filed Aug. 14, 1972, entitled "Tobacco Moisture Control System and Method".

We claim:

1. A method of controlling a tobacco dryer system whereby tobacco having desired characteristics exits the dryer system, said system including a rotating dryer drum which feeds a cooler, said dryer drum including means for heating heat transfer surfaces thereof and means for passing a current of hot drying gas through the drum, said method comprising the steps of measuring moisture responsive properties of the tobacco being dried, in response to the measured properties deriving a first control signal for the temperature of the dryer wall and a second control signal for the flow rate of the gas, and in response to said first and second control signals concomitantly controlling the temperature of the heat transfer surfaces and the gas flow rate.

2. The method of claim **1** further including responding to properties of the tobacco being dried to derive at least one feedback signal, and modifying at least one of said first and second control signals in response to said at least one feedback signal.

3. The method of claim 1 wherein the measuring step includes measuring the moisture and temperature of tobacco exiting the dryer drum, and the first and second control signals are derived by comparing the measured tobacco moisture and temperature with set point values therefor.

4. The method of claim 3 wherein the measuring step includes measuring moisture properties of tobacco entering the drum, and the first and second control signals are derived by combining indications of the measured moisture properties of tobacco entering the drum with the other measured properties.

5. A controller for a tobacco dryer system including a rotating drying drum which feeds a cooler whereby tobacco having desired characteristics exits the cooler, said dryer drum including means for heating heat transfer surfaces thereof and means for supplying heated gas to the drum in a flow direction opposite from the direction the tobacco moves through the drum, said controller comprising means responsive to signals indicative of weight and moisture of tobacco entering the dryer system for deriving a first signal indicative of the dryer duty of the drum to achieve a desired moisture of tobacco exiting the system and a second signal indicative of the dry weight of the input tobacco, means responsive to signals indicative of the specific heat and weight of tobacco entering and exiting the drum for deriving a third signal indicative of the heat energy change induced in the tobacco by the drum on the tobacco passing through the drum, and means responsive to said first, second, and third signals for deriving first and second control signals for the flow rate of the gas and the temperature of the heat transfer surfaces.

6. The controller of claim 1 further including means for concomitantly controlling the gas flow rate and the temperature of the heat transfer surfaces in response to said first and second control signals.

7. The controller of claim 6 further including means responsive to the moisture of tobacco exiting the cooler and a set point for the moisture of the tobacco exiting the cooler for deriving a first error signal, means responsive to the signal indicative of the temperature of tobacco exiting the dryer drum and a set point value for the temperature of tobacco exiting the dryer drum for deriving a second error signal, and means for respectively modifying said first and second control signals in accordace with said first and second error signals.

8. The controller of claim 1 wherein the means for deriving the signal indicative of dryer duty includes computer means responsive to a set point signal for the ratio of the weight of water exiting the cooler to the weight of dry tobacco exiting the cooler.

9. A controller for a tobacco dryer system whereby tobacco having desired characteristics is obtained from an exit of the system, said system including means for controlling the temperature of heat transfer surfaces of the dryer system and means for passing a current of drying gas through the tobacco as the tobacco passes through the dryer system, said controller comprising means for measuring and deriving signals respectively indicative of the moisture and weight of tobacco entering the dryer system of the temperature difference between the tobacco entering the dryer system and of the tobacco exiting the portion of the dryer system where the current of hot gas flows, means responsive to the signals indicative of moisture and weight of tobacco entering the system and the temperature difference for deriving a first control signal for the temperature control means and a second control signal for flow rate of the gas, and means responsive to said first and second control signals for concomitantly controlling the temperature control means and the gas flow rate.

10. In a controller for a tobacco dryer system, said system including means for controlling the temperature of heat transfer surfaces of the dryer system and means for passing a current of hot drying gas through the tobacco as it passes through the dryer system, said controller comprising means for deriving signals indicative of the temperature, moisture and weight of tobacco entering the dryer system and of the temperature of the tobacco exiting the portion of the dryer system where the current of hot gas flows, and means responsive to said signals for deriving a first set point signal for the temperature control means and a second set point signal for flow rate of the gas.

11. The controller of claim 10 further including means for deriving a signal indicative of the moisture of tobacco exiting the system, means responsive to the signal indicative of the moisture pf tobacco exiting the system, means responsive to the signal indicative of the moisture of tobacco exiting the system and a set point signal for the moisture of tobacco exiting the system for deriving a first error signal, means responsive to the signal indicative of the temperature of tobacco exiting the portion of the dryer system where the current of hot gas flows and a set point value for the temperature of tobacco exiting the portion of the dryer system where the current of hot gas flows for deriving a second error signal, and means for respectively modifying said first and second set point signals in accordance with said first and second error signals.

12. A method of controlling a tobacco dryer system, said system including means for controlling the temperature of heat transfer surfaces of the dryer system and means for passing a current of hot drying gas through the tobacco as it passes through the dryer system, said method comprising the steps of measuring the temperature, moisture and weight of tobacco entering the dryer system, deriving a signal indicative of the temperature of the tobacco exiting the portion of the dryer system where the current of hot gas flows, in a computer responsive to signals indicative of the measurements and the signal indicative of exit tobacco temperature deriving a first control signal for the temperature control means and a second control signal for the flow rate of the gas, and concomitantly controlling the temperature of the tobacco and the flow rate of the drying gas in response to said first and second control signals.

13. The method of claim 12 further including measuring the moisture of tobacco exiting the system, responding to the measurement for moisture of tobacco exiting the system and a set point value therefor to derive a first error indication, responding to the measurement for temperature of tobacco exiting the portion of the dryer system where the current of hot gas flows and a set point value therefor to derive a second error indication, and respectively modifying said first and second control signals in accordance with said first and second error indications.

14. A controller for a tobacco dryer system including a rotating drying drum which feeds a cooler whereby

tobacco having desired characteristics exits the cooler, said dryer drum including means for heating heat transfer surfaces thereof and means for supplying heated gas through the drum in a flow direction opposite from the direction tobacco moves through the drum, said controller comprising means for deriving signals indicative of weight and moisture of tobacco entering the dryer system and a signal indicative of the temperature difference of tobacco entering and exiting the drum, and means responsive to said signals for deriving first and second control signals for the flow rate of the gas and the temperature of the dryer walls.

15. The controller of claim **14** further including means for concomitantly controlling the gas flow rate and dryer wall temperature in response to said first and second control signals.

16. The controller of claim **14** wherein said means for deriving said first and second control signals includes: means for computing dryer duty, means for computing the heat energy change induced by the drum on the tobacco passing through the drum, and means for computing bone dry basis weight of the tobacco passing through the drum.

17. The controller of claim **16** wherein the means for computing the heat energy change induced by the drum on the tobacco passing through the drum includes: means responsive to the moisture of tobacco entering the dryer drum for deriving a signal indicative of the specific heat of the tobacco entering the dryer drum, and means responsive to the signal indicative of the specific heat and the signals indicative of the temperature difference of the tobacco entering and exiting the dryer drum and the signal indicative of the weight of the tobacco entering the dryer drum.

18. The controller of claim **16** wherein the means for deriving the first and second control signals includes memory means responsive to the signals indicative of dryer duty, bone dry weight of tobacco, and heat energy change induced by the drum on the tobacco for deriving the first and second control signals.

19. A controller for a tobacco dryer system whereby tobacco having desired characteristics exits the dryer system, said system including a rotating dryer drum which feeds a cooler, said dryer drum including means for heating heat transfer surfaces thereof and means for passing a current of hot drying gas through the drum, said controller comprising means for measuring moisture responsive properties of the tobacco being dried, means responsive to the measured properties for deriving a first control signal for the temperature of the dryer wall and for deriving a second control signal for the flow rate of the gas, and means responsive to said first and second signals for concomitantly controlling the temperature of the heat transfer surfaces and the gas flow rate.

20. The controller of claim **14** further including means responsive to properties of the tobacco being dried for deriving at least one feedback signal, and means for modifying at least one of said first and second control signals in response to said at least one feedback signal.

21. The controller of claim **19** wherein the means for measuring includes means for deriving signals indicative of moisture and temperature of tobacco exiting the dryer drum, and the means for deriving the first and second control signals includes means for comparing the derived signals for tobacco moisture and temperature with set point values therefor.

22. The controller of claim **20** wherein the means for measuring includes means for deriving further signals indicative of moisture properties of tobacco entering the drum, and the means for deriving the first and second control signals further includes computer means responsive to the further signals.

23. A controller for a tobacco dryer system including a rotating drying drum which feeds a cooler whereby tobacco having desired characteristics exits the cooler, said dryer drum including means for heating heat transfer surfaces and means for supplying heated gas through the drum, said controller comprising means responsive to signals indicative of moisture and weight of tobacco entering the dryer system and of the temperature difference of tobacco entering and exiting the drum for deriving first and second set point signals for the temperature of the dryer and the flow rate of the gas, means responsive to the moisture of tobacco exiting the cooler and a set point for the moisture of the tobacco exiting the cooler for deriving a first error signal, means responsive to the signal indicative of the temperature of tobacco exiting the dryer drum and a set point value for the temperature of tobacco exiting the dryer drum for deriving a second error signal, and means for respectively modifying said first and second set point signals in accordance with said first and second error signals.

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