April 9, 1968 L. V. FEGAN, JR 3,376,877

MOIST FEED MIX AIR PERMEABILITY CONTROL

Filed May 9, 1966 4 Sheets-Sheet 1

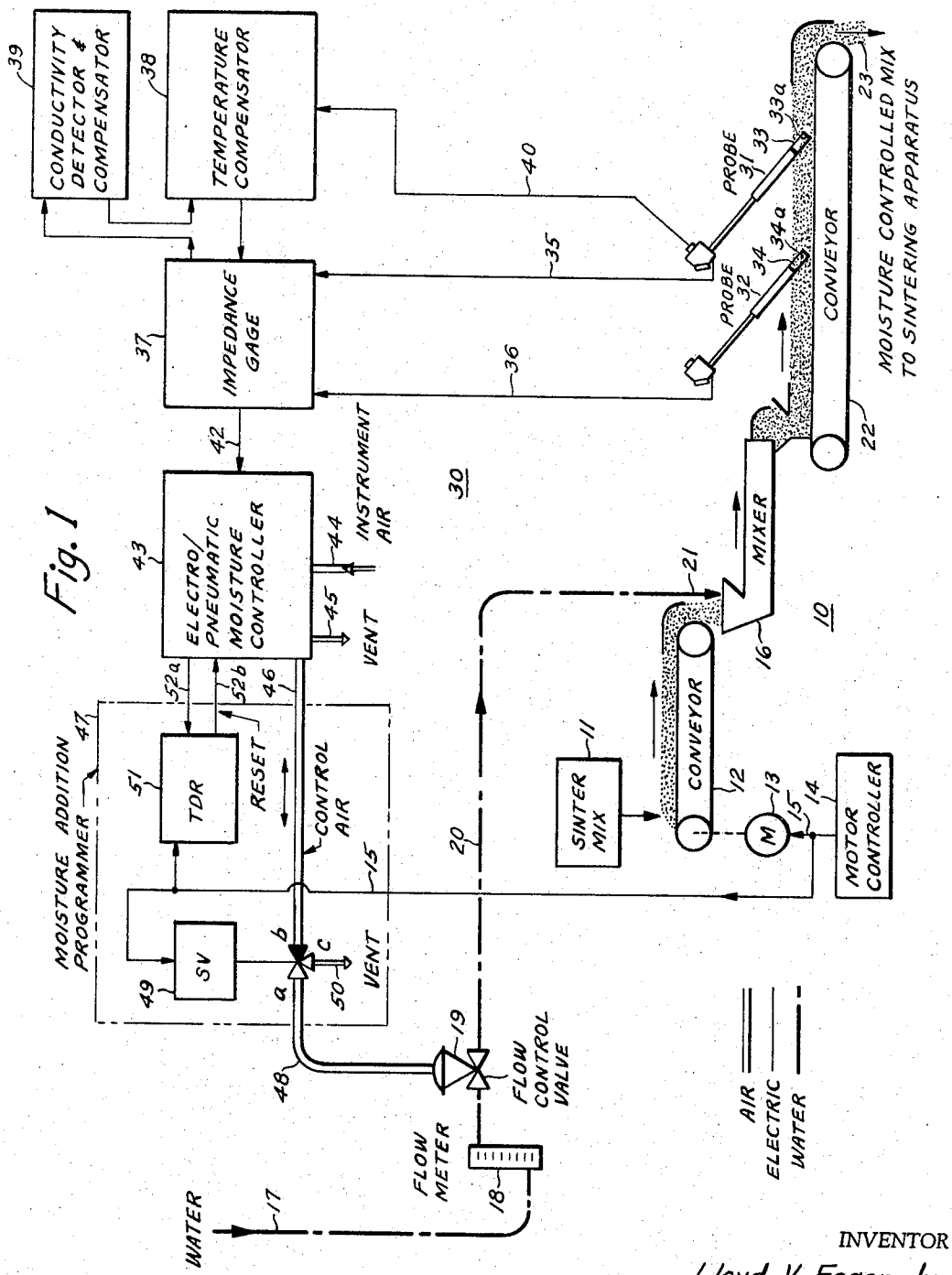

Fig. 1

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MOIST FEED MIX AIR PERMEABILITY CONTROL

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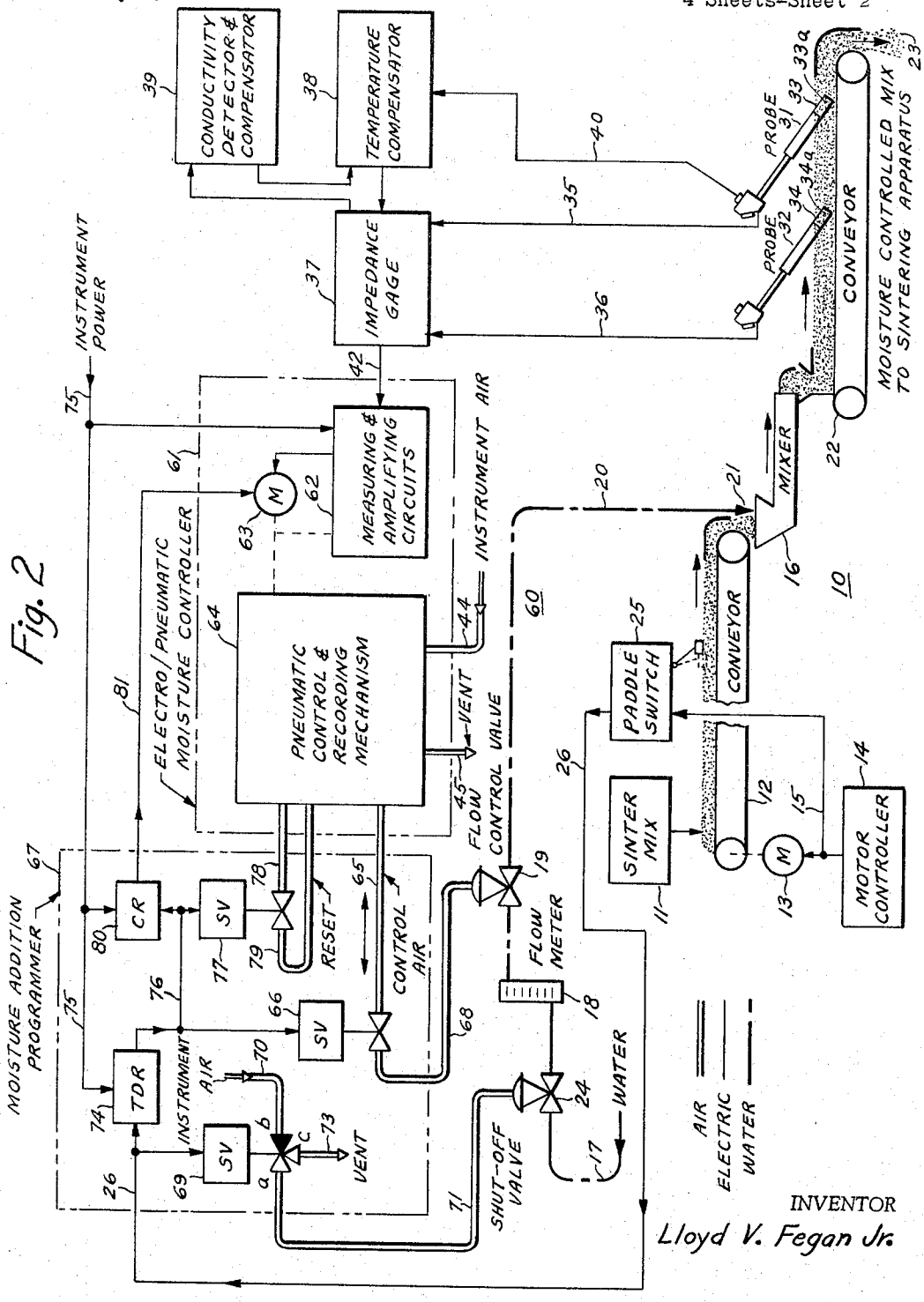

Fig. 2

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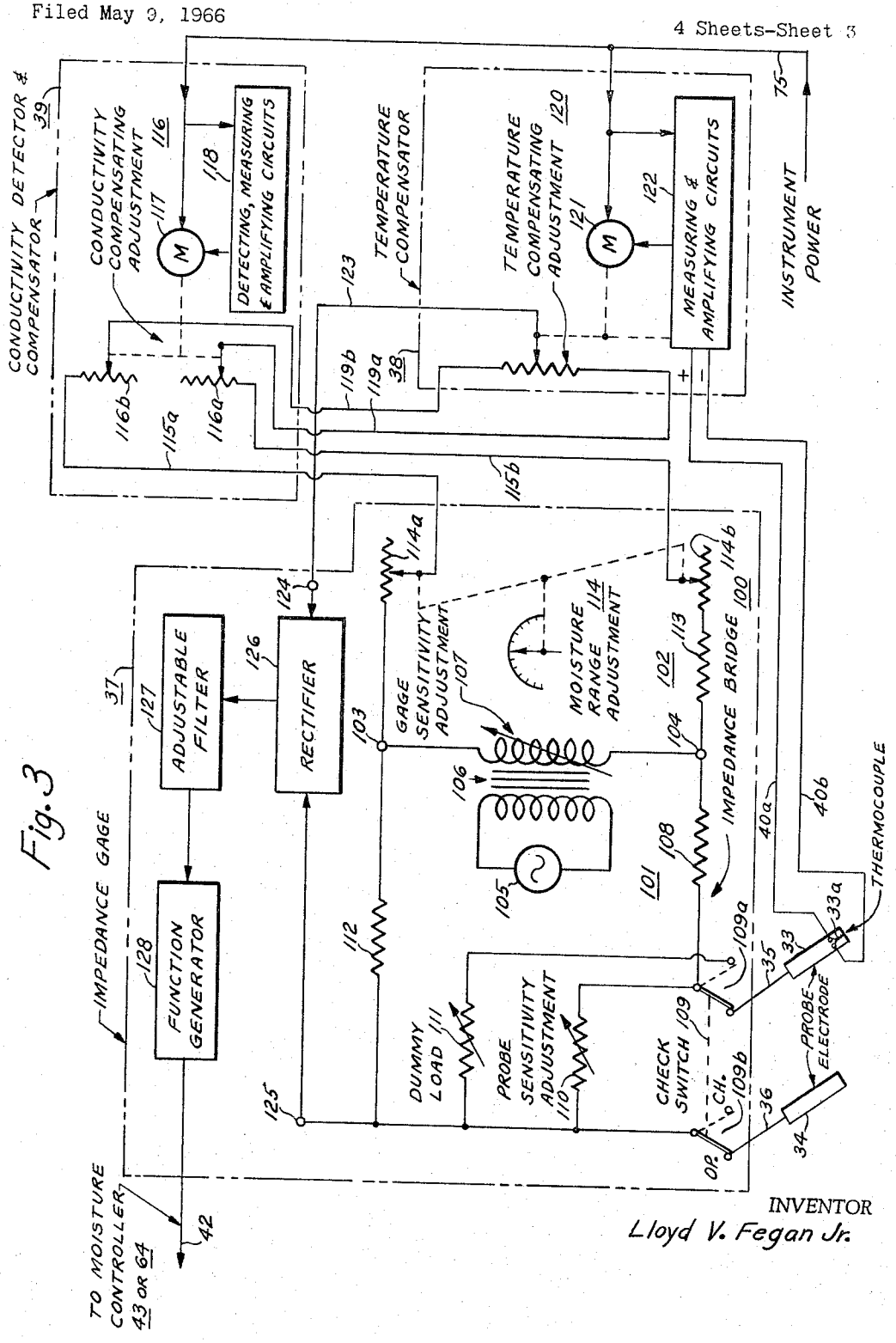

Fig. 3

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MOIST FEED MIX AIR PERMEABILITY CONTROL

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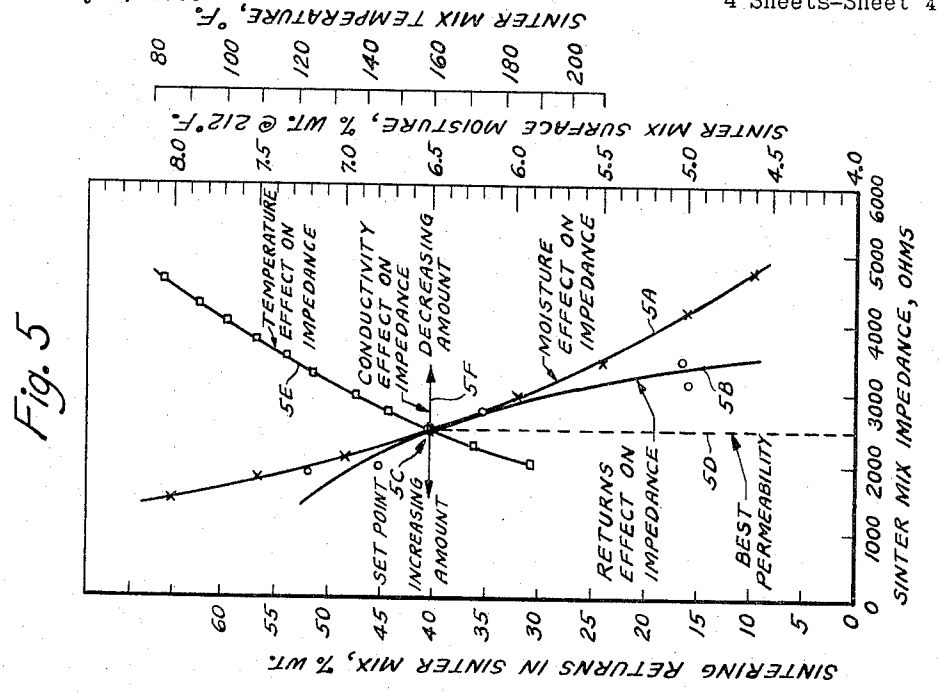

Fig. 5

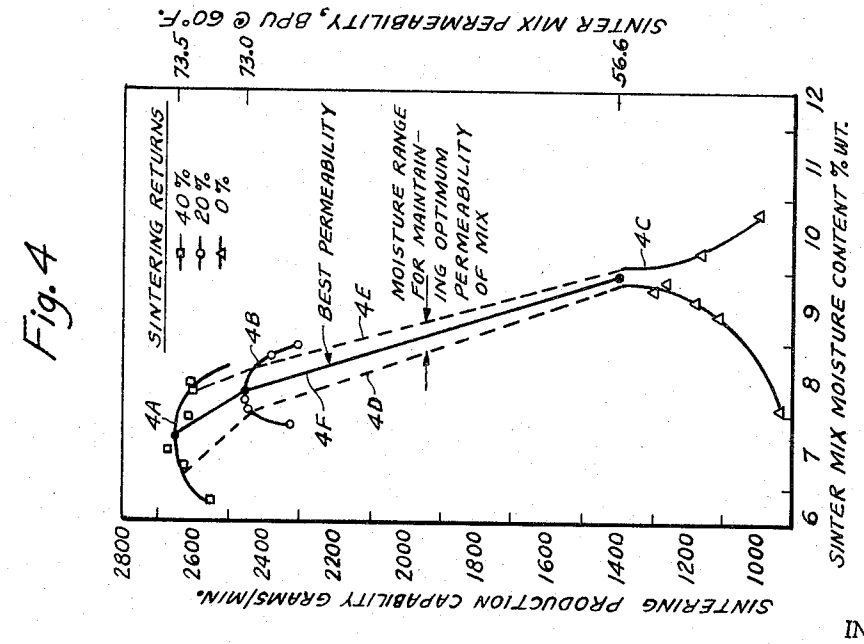

Fig. 4

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United States Patent Office 3,376,877
Patented Apr. 9, 1968

3,376,877

MOIST FEED MIX AIR PERMEABILITY CONTROL

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Filed May 9, 1966, Ser. No. 548,757
22 Claims. (Cl. 134—57)

This invention relates to condition-responsive apparatus for controlling the air permeability of a moist mix of particulate materials through measurement and control of the mix moisture content by electrical impedance methods.

Contemporary ferrous and non-ferrous ore reduction apparatus operate in dependency on a high grade concentrated raw material supplied in the form of a sintered or pelletized product resulting from beneficiating low grade ores. In a well-known sintering process of beneficiating ferrous ores, for example, a moisture deficient mix of proportioned amounts of iron ore, or a blend of ores, limestone, coal or coke, Flue dust and mill scale, together with both hot and cold sintering returns, are combined in a pug mill, or other mixer, with controlled amounts of moisture to produce a highly abrasive agglomerated mix.

In the beneficiating process the mix requires a prescribed value of air permeability for efficient sintering operations. Air permeability is regulated by material particle sizes, which in this instance range from about 3/8" to 100 mesh and finer in varying size-consist, and the amount of surface moisture on and between the material particles and not the absorbed and chemically combined moisture. Each mix formula requires a prescribed amount of surface moisture in relation to the amount of sintering returns to achieve the best air permeability of the mix. Higher amounts of moisture are required for low returns content, and vice versa. However, there is an optimum moisture range permissible where best permeability is substantially unaffected. This range is critical at low amounts of returns and somewhat less stringent at higher levels of returns, it being desirable to maintain the proper amount of surface moisture at all times. For example, if the feed mix is too wet, sufficient air and hot gases can not be applied to permeate the mix for burning the coal or coke, and if too dry the fines will blow through the bed. Both of these conditions cause an inferior sintered product and require a reduction in sintering production rate.

Thus, it is essential to accurately measure and closely control the moisture content in the feed mix in order to achieve the best air permeability, and subsequently maximum production rates, while maintaining high uniform quality of sintered product. Since the sintering process is a continuous one, the feed mix moisture measurement and control should also be on a continuous basis, but programmed according to the correct delivery of moisture deficient materials for moisture treatment and the mass movement of treated materials to the sintering machine.

Heretofore, a full time attendant continuously inspected the feed mix delivered to every sintering machine used in a plant. He visually determined its moisture content and accordingly regulated the amount of moisture added to the mix. This manual measurement and control was not only expensive but inaccurate while seldom ever achieving best production capabilities. An attempt to use a nuclear radiation gaging system for determining total moisture content (surface, absorbed and chemically combined amounts) in sintering mixes on a bulk density basis met with limited success. However, it provided not only expensive but necessitated frequent (daily) calibration in addition to being incapable of determining surface moisture requirements for best air permeability as sintering returns varied. Moreover, it was sensitive to the hydrogen atoms in the mix materials and varied the total

moisture content when none was required for adjusting the air permeability of the mix. Other conventional systems have been tried and found deficient in one respect or another.

The present invention utilizes an electrical phenomenon related to air permeability and corresponding to the particle content and surface moisture content of the feed mix. More particularly, an improved electrical impedance probe system, compensated for temperature and conductivity effects on detected impedance, continuously monitors feed mix impedance and interprets it in a fixed relation to air permeability and variable relation to surface moisture content of the mix. The electrical impedance varies non-linearly with respect to both moisture content and amount of sintering returns in the feed mix. The impedance decreases as the amount of either moisture or returns increases, and vice versa. However, in a properly moistened feed mix, the amount of moisture required varies inversely as the returns vary. Thus, when these properties vary, as they do in practice, their effects on mix impedance offset each other and produce a substantially constant impedance value for the best air permeability regardless of the amount of returns in the mix, within operating limits.

A moisture measurement and control system utilizes this phenomenon whereby a control signal representative of mix impedance corrected for temperature and conductivity effects acts on a moisture addition controller having proportional and reset action. This varies amounts of addition water moisture effects thereon, since higher returns require less moisture, and vice versa. There remains then a substantially constant impedance value which when compensated to variations in temperature and conductivity effects coincidentally represents the best permeability factor of the mix at the various percentages of sintering returns therein. This compensated measurement is used as a basis for signaling moisture addition apparatus as required to maintain constant mix impedance, thereby accurately maintaining moisture content in, and best air permeability of, the mix over protracted periods of usage. The utilization of this phenomenon is also applicable to other types of moist particulate mixes.

One of the objects of this invention is to provide apparatus for accurately controlling the air permeability of a movable mass of particular materials subjected to moisture addition treatment.

Another object of this invention is to provide apparatus for accurately measuring and controlling the surface moisture content in a movable mass of ore feed mix subjected to moisture addition treatment prior to sintering or pelletizing operations.

A further object of this invention is to provide apparatus for continuously and accurately measuring surface moisture content in a movable mass of ore feed mix and accurately controlling the air permeability of the mass responsive thereto prior to sintering operations.

Still another object of this invention is to provide condition-responsive apparatus for programming moisture addition to a movable mass of particulate materials subjected to moisture treatment.

Yet another object of this invention is to provide condition-responsive apparatus operable in dependency on electrical impedance characteristics of the movable mass of particulate materials for accurately measuring and controlling surface moisture content in said mass.

Further, another object of this invention is to provide condition-responsive apparatus for accurately measuring electrical impedance characteristics of a movable mass of particulate materials and automatically compensating the measurement for temperature and conductivity effects on said impedance.

These and other objects and features of the present invention will become apparent in the following description and accompanying drawings wherein like numerals represent the like parts in the several views:

FIG. 1 is a schematic diagram of one form of condition-responsive apparatus of the present invention.

FIG. 2 is a schematic diagram of another form of condition-responsive apparatus of the present invention.

FIG. 3 is a schematic electrical diagram of an impedance gage incorporating temperature and conductivity compensating circuits as employed in the apparatus of the present invention.

FIG. 4 is a Cartesian plot of physical characteristics of an iron ore sintering feed mix.

FIG. 5 is a Cartesian plot of electrical impedance characteristics of an iron ore sintering feed mix.

Briefly, the present invention comprises improved probe means for detecting the electrical impedance of a movable bed of iron ore sintering feed mix downstream of a moisture spray head and for signaling the co-related temperature of said mix, impedance responsive measuring means for producing a control signal proportional to detected impedance and corresponding to the surface moisture content of said mix, said measuring means including compensating means responsive to said temperature signal and a conductivity signal determined elsewhere in the sinter mix for correcting the detected impedance against the effects of such variables, and means operatively associated with said moisture spray head and responsive to the control signal for automatically adding controlled amounts of moisture to maintain a uniform compensated impedance level and thereby the best air permeability factor under varying processing conditions. Included in the latter means are alternative moisture addition programmers operative under control of command signals representing the movement and/or presence of said feed mix, and a moisture controller responsive to said control signal which is modified to prevent reset control accumulation during shutdowns.

It is common practice in ore sintering plant operations to prepare moisture deficient feed mixes using substantially constant proportions of ore and other materials and varying amounts of sintering returns. Addition water is varied to maintain the best air permeability of the moisture treated mix fed to the sintering machines. In an investigation of the physical and electrical properties of the feed mixes, numerous laboratory specimens were prepared having a moisture deficient blend of ores selected from El Pao and Cerro Bolivar ores from South America, Labrador ore from Newfoundland and Nimba ore from Africa, combined with flue dust both wet and dry, coal and limestone, in addition to varying amounts of both hot and cold sintering returns.

Mix A had a burden which included 40% sintering returns, the screen analysis for which is as follows: +6 mesh—38.4%, +100 mesh—51.5%, +200 mesh—5.4%, and −200 mesh—4.7%. Mix B had a burden prepared in a similar manner using only 20% returns, the screen analysis of which is as follows: +6 mesh—29.7%, +100 mesh—58.1%, +200 mesh—5.8%, and −200 mesh—6.4%. Mix C had a burden prepared without any sintering returns. Varying amounts of moisture were added during mixing in a laboratory mixer and samples were withdrawn and dried to a constant weight at about 212° F. Weight differences were noted as amounts of surface moisture content. The remaining portion of each mix was prepared as a box sample and fired statically over a grate while observing data for calculating British Permeability Units. Laboratory data on physical properties is exemplified in the Cartesian plot of FIG. 4. Curve 4A corresponds to Mix A and shows that the best air permeability is obtained by a mix having 40% returns and a minimum amount of moisture content. Curve 4B is representative of Mix B showing that a mix having 20% sintering returns has less permeability and requires more moisture than Mix A having 40% sintering returns. Curve 4C corresponds to Mix C wherein 0% sintering returns were included in the feed mix, this requiring the greatest amount of moisture and the least permeability. Curves 4D and 4E identify an optimum air permeability for the foregoing mixes and Curve 4F shows their best air permeability, there being a correspondence of permeability with sintering production capability.

A study of the electrical phenomenon of similar mixes was carried out on production apparatus where it was far easier to observe the individual effects on electrical impedance by independently varying the amounts of sintering returns, moisture content and temperature of the mix, and conductivity of the flue dust constituent, for example, one at a time. Results of these observations are illustrated in the Cartesian plot of FIG. 5, which represents various electrical properties of foregoing types of mixes. Curve 5A shows the moisture effects on probe detected impedance which shows a non-linear increase in impedance as the amount of surface moisture decreases, and vice versa. Curve 5B illustrates the varying sintering returns effect on impedance which also varies non-linearly to cause an increase in impedance as the amount of sintering returns decrease, and vice versa.

It will be observed that when the sinter mix contains the proper amount of moisture for a prescribed amount of sintering returns (FIG. 4) such as occurs at 40% returns and 6½% surface moisture, that Curves 5A and 5B become tangent at a point 5C referred to hereinafter as the set point. If the moisture content should increase while returns remain constant, then the impedance decreases to a value determined by projecting a vertical line to intersect Curve 5A at the appropriate amount of moisture. Likewise, if the returns decrease, thus causing a corresponding increase in impedance. This is determined by projecting a vertical line to intersect Curve 5B at the appropriate amount of returns. Should both moisture content and returns vary correspondingly according to the data of FIG. 4, then the resulting decrease in impedance effected by an increase in moisture would offset the increase in impedance effected by decrease in returns so that a straight line drawn between their respective values on Curves 5A and 5B would intersect set point 5C. This relationship is substantially constant for all values of best air permeability, thus producing a constant impedance value for all permeability factors and is shown as line 5D in FIG. 5.

Curve 5E illustrates temperature effects on detected impedance while other factors remain substantially constant. This shows that a sinter mix having 6½% moisture, 40% returns and operated at a temperature of 160° F., had about 2500 ohms impedance. As the temperature was increased from 160° F., the impedance decreased from set point 5C. As the temperature was decreased from 160° F., the impedance increased non-linearly. Curve 5E is adjusted somewhat to compensate for the evaporation losses of the moisture in the mix as temperature was raised.

Curve 5F illustrates conductivity effects on impedance, which effects were attributed to varying amounts of flue dust which have a significant amount of chloride content. As the conductivity decreased the impedance increased and vice versa, to shift the set point 5C horizontally.

Thus, it is possible to employ the above phenomenon in impedance-responsive apparatus for measuring and controlling the moisture content, and consequently the air permeability, of the sinter mix when compensating the impedance measurements for temperature and conductivity effects on the electrical properties of the sinter mix.

Turning now to FIG. 1 there is illustrated schematically a simple form of accurately measuring the impedance of a sinter mix and compensating it for temperature and conductivity effects thereon, and controlling the moisture content of the feed mix by the addition of

controlled amounts of water in response to the impedance signal. More specifically sintering feed mix apparatus 10 receives dry or insufficiently wet materials of the foregoing description fed from source 11 on to moving conveyor 12, the conveyor 12 being driven by motor 13 supplied by current from motor controller 14 over conductor 15. Materials deposited on conveyor 12 are delivered to a mixer 16 which in the case of sintering feed mixes is a pug mill, or other suitable apparatus. Water is fed over conduit 17 to an optional flow meter 18, through flow control valve 19, over a conduit 20, and delivered to spray head 21 at mixer 16. When preparing sinter mixes, the particulate materials are mixed with controlled amounts of water to produce a fluffy feed mix having a prescribed air permeability. The moistened feed mix issued from mixer 16 is dropped a short distance to the movable conveyor 22 to provide a uniform compaction of its constituents in preparation for impedance detection, thus avoiding one significant variation which may occur in impedance characteristics of the moveable mix. The moisture controlled sinter mix 23 is delivered for subsequent use in sintering apparatus. In the foregoing characterized steps, conveyors 12 and 22 and mixer 16 are considered to be operating in unison during processing to move the abrasive feed mix materials at speeds up to about 325 feet per minute with respect to stationary impedance measuring probes hereinafter described.

Sintering feed mix moisture is measured and controlled by condition-responsive apparatus 30 which operates to detect sinter mix impedance at a pair of probes 31 and 32. This impedance is compared in a gaging device against adjustable standards which delivers an electrical control signal proportional to temperature and conductivity corrected impedance. The electrical control signal is applied to an electro-pneumatic controller where it is converted from an electrical signal to a pneumatic signal. The latter signal operates on the diaphragm motor of flow control valve 19 to control water addition and maintain a substantially constant impedance between the probes, thereby maintaining the best air permeability of the feed mix.

Probes 31 and 32 are preferably of a temperature signaling, impedance detecting, variety as described and claimed in my copending application filed on even date herewith, entitled "Temperature Signaling Impedance Probes." The single electrode type have been found effective in detecting the electrical impedance of the aforementioned sintering mix while signaling its co-related temperature. Each of the brobes have an abrasion-resistant operating end which includes a tungsten carbide electrode contact area 33, 34, and high density refractory insulator material circumscribing the electrode areas which serve to provide accuracy in measurement of impedance over protracted periods of usage.

Incorporated in probe 31, and alternatively in probe 32, is a temperature sensing means, which for the purposes of the present invention, is a thermocouple but may be a thermistor or other device. Further, probe assemblies are utilized in which the probes are pivotally mounted, and optionally biased, so as to provide uniform contact with sinter mix during undulations in the treated feed mix. Other one-and two-electrode temperature signaling probes are also disclosed in the co-pending application including probe assembly combinations ranging from tandem to side-by-side arrangements and unitary probe installations. The tandem installation is preferred when using the above feed mix at the aforementioned velocities. Under these conditions, the probes are spaced about 20 inches apart along the longitudinal centerline of conveyor 22 in order to derive a suitable impedance sensitivity having minimal fluctuations due to size-consist variations, this being about 2500 ohms for the best air permeability of the sinter mix. In other feed mixes where, for example, the chloride content is high and the best permeability impedance may be substantially lower than this, probe spacing may be as much as 10 feet in order to achieve an impedance sensitivity with in a range of about 300 to 3000 ohms. Conversely, if the moistened feed mix consists of a single ore, a carbonaceous fuel or another optional adjuvant its best permeability impedance may be many thousands of ohms, thus requiring a unitary probe having a pair of closely spaced electrodes and a temperature sensitive device.

Impedance signals detected at probes 31 and 32 are delivered over conductors 35 and 36, respectively, to impedance gage 37 which is later described in connection with FIG. 3. The impedance gage is also operative in dependency on the corrective effects of temperature compensator 38, and optionally conductivity compensator 39. In operation, an AC signal is impressed on the moistened mix and the gage converts varying impedance values to proportional DC output signals ranging from about 0 to 30 millivolts which are corrected for normally error producing effects of temperature and conductivity. The impedance gage is circuited and calibrated to produce about 15 mv. output at the best air permeability impedance which output signal varies inversely proportional to compensated impedance and is optionally corrected for non-linearities in mix impedance.

The temperature signal from thermocouple 33*a* in probe 31 is delivered over circuit 40 to temperature compensator 38, a conventional servo-driven temperature recorder having a transmitting slide wire connected in circuit in the impedance gage 37 as will be later described. The temperature controller has a fast response speed and is calibrated to produce an offsetting effect on detected impedance in accordance with Curve 5E in FIG. 5 so that the output signal of impedance gage remains constant as mix temperature varies. Over-compensation effects may also be included in its calibration to offset moisture evaporation characteristics of the mix, the amount being determined by environmental and operating characteristics of the moisture treating process.

Conductivity detector and compensator 39 operates to correct the impedance detected at probes 31 and 32 in response to signals delivered to its input circuit which corresponds to electrochemical effects on the moisture treated mix. Such effects may be caused by varying initial amounts of chloride content in flue dust and/or addition water. For automatic operation, compensator 39 is preferably a conventional servo-driven recorder having a pair of transmitting slide wire rheostats operative in gage 37 circuitry to offset the conductivity effects on impedance shown at line 5F in FIG. 5 as will be explained below. Alternatively, the servo-drive may be replaced by manually operated rheostats calibrated in terms of conductivity effects on the mix.

Impedance gage 37 output is delivered over circuit 42 to the input of electro-pneumatic moisture controller 43. Controller 43 is a conventional electronic controller having two-mode control action, i.e., proportional plus reset action. Proportional action includes an adjustable set point, indexed at about 70% scale, and produces a throttling effect on moisture addition at spray head 21. The reset action causes a shifting of the controller's throttling range to various stabilized values proportional to the magnitude, duration and direction of input signal excursions at circuit 42. This is caused by an uncorrected change in detected impedance each time it varies from the set point. This effect causes flow control valve 19 to adjust to corresponding stabilized values for each excursion in control signal from set point. Controller 43 has a pneumatic transmitter operative in response to its internal electronic signal and receives instrument air at 20 p.s.i. over conduit 44, and vents used air through conduit 45 to atmosphere, thus providing a pneumatic control signal over conduit 46 to moisture addition programmer 47. From there it is carried over conduit 48 to the pneumatic operator on flow control valve 19 and causes the valve to throttle from 0 to 100% corresponding to a 3 to 15

p.s.i. control air signal provided by the pneumatic transmitter.

Moisture addition programmer 47 includes a three way solenoid valve 49 for preventing the passage of control air through its ports *a–b* while venting the pneumatic operator on valve 19 via conduit 48, ports *a–c*, and conduit 50, when deenergized, thus closing flow control valve 19. When a command signal is received over circuit 15, solenoid valve 49 is energized and blocks port *c* and allows the passage of control air through ports *a–b*. This opens valve 19 immediately to a position according to the pneumatic control signal pressure and allows water addition to proceed.

Moisture addition programmer 47 also includes a time delay relay 51 circuited to incapacitate the reset function of controller 43 by means of conductors 52*a* and 52*b* and contact closure when its operating coil is deenergized. This prevents reset signal from accumulating when controller 43 is off set point during shutdown. When operation is restored as evidenced by a command signal delivered over conductor 15, time delay relay 51 will become energized and restore the reset function after a prescribed time delay selected to be consistent with system operating conditions. Solenoid valve 49 may be eliminated from programmer 47 when impedance gage 37 is circuited and calibrated to cause maximum control signal to appear at circuit 42 when the feed mix is not present across probes 31 and 32. This gage feature will cause controller 43 to deliver its minimum signal and shut off flow control valve 19, thus obviating the need for solenoid valve 49.

Still referring to FIG. 1, the operation of condition-responsive apparatus 30 will now be explained. Assuming that an adequate supply of moisture deficient sinter mix 11 is present throughout sinter feed mix apparatus 10, and that conveyors 12 and 22 and mixer 16 are operating, thus energizing solenoid valve 49 and time delay relay 51 which cause a flow of addition water at spray head 21 and allow controller 43 to function normally. Assuming further that moisture treated feed mix delivered at 23 has an impedance of 2500 ohms when its moisture content is 6½%, its returns 40%, and the mix temperature 160° F., this point being identified as set point 5C in FIG. 5 and also corresponds to the set point adjustment in controller 43.

Under these operating conditions, the impedance detected across probes 31 and 32 as measured by impedance gage 37 produces an output signal about midway in its range. Impedance gage 37 output signal is delivered to controller 43 which will deliver a proportional pneumatic control signal over conduit 46, through solenoid valve 49. Solenoid 49 became energized by a command signal over circuit 15 when conveyor drive motor 13 is energized by circuit 15, thus signifying movement of sinter mix material and allowing moisture to be added, if required, by the passage of pneumatic control signal through ports *a–b*, port *c* now being blocked. The control signal passes through conduit 48 to act on diaphragm motor of flow control valve to cause it to open to about its midpoint position. Under this condition, water is delivered via conduit 17 and flow meter 18, through flow control valve 19 and conduit 20 to spray head 21. Valve 19 is adjusted by the pneumatic control signal to deliver a steady flow of addition water to the materials supplied to mixer 16 to maintain a constant impedance of about 2500 ohms in the feed mix delivered at 23, thereby maintaining the best air permeability as illustrated at the midpoint of Curve 4A in FIG. 4.

Assuming now that the amount of sintering returns in mix 11 have dropped to 20%. In practice these returns are a mixture of mostly hot coarse materials and some cool fine materials, but the total amount added to mix 11 is dry. According to the curves of FIG. 5, the returns effect will momentarily increase impedance to a value above the 2500 ohms level at line 5D.

The increase in impedance causes impedance gage 37 output to decrease, thus causing pneumatic controller 43 output pressure at conduit 46 to reduce and partially close flow control valve 19 and reduce the previous rate of water addition. The reduction in water addition rate is occasioned by a proportional reduction of dry ingredients mixed with the other materials which results in a momentary excess of moisture content. The impedance detected across probes 31–32 lowers as the water addition becomes less and stabilizes at about 2500 ohms while providing the correct amount of moisture in the mix, this amount being a higher percentage than when the amount of returns were higher. This effect may be followed along the curve of FIG. 5.

For each reduction in returns a momentary increase in impedance will occur, thus causing impedance gage output signal to act on controller 43 and its pneumatic signal to act on flow control valve 19 to further reduce water addition flow rates. The control action will be the same as above where the amount of addition water is adjusted to stabilize the mix impedance at 2500 ohms.

As the amount of returns are increased, such as from 0% upward to 40%, the opposite changes take place in impedance and control functions. In each instance where the percentage returns are varied a control action stabilizes only after the impedance level is returned upward to 2500 ohms and controller 43 returns to its set point. Even though the effect of controller reset action causes varying shifts in a throttling range to occur, the mix impedance will stabilize and cause the right amount of water addition to make the moisture content to conform to the Curves of 4A, 4B and 4C. Bearing in mind that as returns increase there are more fines being agglomerated between the large particles in the mix, thus leaving less room for moisture to be held but at the same time requiring less percentage of surface moisture content to maintain best permeability.

Some momentary disturbances in the process control system such as a momentary change in times or the amount of initial moisture and the insufficiently wet materials may cause some change in a set point. This would cause an impedance change in the corresponding action on moisture controller 43 which results in changing the addition water flow rate at valve 19 to cause changes in moisture content. However, these are generally kept within the limits defined by Curves 4D and 4E which also indicate the non-linearities in moisture content with respect to returns and air permeability.

If moisture content should increase thus causing a temporary reduction an impedance to a value less than 2500 ohms the controller 43 will act in the same manner as it did for an increasing amount of returns described above so that an increase in water flow rate occurs, this being accompanied by a reduction in percentage moisture content in the mix.

The operating details of temperature compensator 38 and conductivity compensator 39 will be explained in detail in connection with FIG. 3 below.

Still referring to FIG. 1, when conveyor drive motor 13 fails to move material; the command signal at circuit 15 ceases and deenergizes solenoid valve 49 and time delay relay 51 in moisture addition programmer 47. Controller 43 is immediately rendered ineffectual by the action of solenoid valve 49 whose port *b* becomes blocked and passage through ports *a–c* exhausts control air pressure through vent conduit 50, thus closing flow control valve 19 and shutting off water flow at spray head 21. Simultaneously, time delay relay 51 is deenergized and through its contact arrangement with reset circuit 52*a*–52*b*, immediately incapacitates controller 51 reset action, thus preventing any reset accumulation from occurring if the controller is instantaneously operating off of its set point.

When power is restored to circuit 15, solenoid valve 49 becomes energized thus causing the flow of control air through ports *a–b* which formerly was blocked at port *b* at its last level before loss of material movement. Port *c*

is now blocked and control air flows through conduit 48 to the pneumatic operator on valve 19 which restores water flow at spray head 21, if needed. Reset action of controller 43 having been in hold condition prevented a deluge of water from being added to the feed mix due to an inherent characteristic of the controller. Reset action will be restored when time delay relay 51 has timed out according to its predetermined setting.

Referring now to FIG. 2, there is shown another form of condition-responsive apparatus having an electric-pneumatic moisture controller, and an improved moisture addition programmer which provides more rapid, smooth and precise restoration of moisture addition to a feed mix responsive to interruptions in the continuous flow of the right quantity of process materials. All other processing and control components and their operation are the same as the embodiment in FIG. 1.

Processing apparatus 10 is provided with a supply of moisture deficient sinter feed mix 11 deposited to a predetermined depth on conveyor 12. Conveyor 12 is driven by motor 13 fed from motor controller 14 over circuit 15. The material issuing from conveyor 12 is deposited in mixer 16 where it is treated with addition water supplied over conduit 17 to shut-off valve 24, through flow meter 18 and flow control valve 19 and via conduit 20 to spray head 21 at the entrance of mixer 16. Mixer 16 distributes addition moisture and mix particles while uniformly fluffing them and later discharging them onto conveyor 22 where the moisture treated mass 23 is delivered to subsequent sintering apparatus. It is also assumed as above that conveyor 12, mixer 16 and conveyor 22 operate in unison to provide a continuous flow of materials and that if the operation of one is interrupted they all follow. A command signal originating at circuit 15 and indicating that material is not moving, this being opposite of FIG. 1 embodiment, is fed to paddle switch 25 having normally opened contacts when there is a deficiency in feed mix level on conveyor 12, these contacts closing at a prescribed feed mix level and issuing the command signal over circuit 26 to moisture addition programmer 67 described below.

Mix impedance is detected by a pair of probes 31 and 32 as in the previous condition-responsive control apparatus 30. Mix temperature is also signaled from at least one of the probes as previously explained. Imepdance signals are conducted over circuits 35 and 36 to impedance gage 37 where they are corrected for effects of temperature and conductivity by temperature compensator 38 and conductivity compensator 39, respectively.

The electronic control signal output from impedance gage is delivered over circuit 42 to electro-pneumatic moisture controller 61. Controller 61 is a conventional electro-pneumatic servo-driven recording-controller but somewhat different from controller 43. One type that is useful is a Minneapolis-Honeywell (M-H) Type 152 which also has two modes of control action, i.e., proportional plus reset action, which operates in dependence of an electronic signal supplied at its input to deliver a pneumatic control signal at its output.

Briefly, an electronic control signal is delivered over circuit 42 to measuring and amplifying circuits 62 where instrument power from line 75 is caused to vary in amplitude and phase relationship proportional to the control signal at 42. This phase sensitive signal, along with instrument power from 75 are applied to servo-motor 63 and drive it in either direction of a null point. Included in controller 61 is a pneumo-mechanical recording and control mechanism 64, responsive to shaft movement of servo-motor 63, which includes a recording pen, a pneumatic relay including both pnuematic poprortioning and reset mechanisms operatively associated with pen movement, and a set point having an adjustable index about which the recording pen operates, depending on the magnitude of electronic input signal. The set point is adjusted to provide a pneumatic control signal proportional to the electronic signal applied from circuit 42, this being in correspondence with the proper best permeability impedance as detected across probes 31 and 32 and corrected by the compensating devices 38 and 39. Reset action shifts the controller's throttling range each time the electronic input signal deviates from set point as explained above.

In normal operation, recording and controlling mechanism 64 receives instrument air at about 20 p.s.i. over conduit 44, vents used air through conduit 45 to the atmosphere, and produces a 3–15 p.s.i. pneumatic control signal at the output of controller 61. This pneumatic signal is delivered over conduit 65 to normally open solenoid valve 66 in moisture addition programmer 67. From there it is carried over conduit 68 to the pneumatic operator on flow control valve 19 and acts to cause a corresponding 9 to 100% throttling of valve 19, thus controlling water addition to sinter feed mix 11.

Moisture addition programmer 67 is constructed to operate in a "hold" condition when there is an absence of movement of sinter mix 11 on conveyor 12 and/or an insufficient level thereof as detected by paddle switch 25. When the deficiency in sinter mix quantity is corrected, moisture programmer 67 releases the "hold" condition and allows the normal control functions to occur.

Programmer 67 includes solenoid valve 69 which has pneumatic passage between ports *a–c* when deenergized while blocking port *b* where instrument air at about 30 p.s.i. is fed over conduit 70. When energized, ports *a–b* allow passage of instrument air and port *c* is blocked. In its energized state, solenoid valve 69 vents the pneumatic operator of normally closed shut-off valve 24 through conduit 71, ports *a–c* and conduit 73, thus allowing shut-off valve 24 to be closed and instantly shut off the water supply at spray head 21 when there is a deficiency in sinter mix level or movement. When energized by command signal at 26, solenoid valve 69 port *c* becomes blocked and ports *a–b* allow passage of instrument air to instantly open valve 24 and permits the throttling action of valve 19 to control the addition water at spray head 21.

Time delay relay 74 has an operating coil connected to circuit 26 and has a set of electrically isolated, normally closed contacts which open at a preset interval after the operating coil is energized, the interval being adjusted according to operating conditions. Its contacts are circuited through 76 to the coils of solenoid valves 66 and 77 and control relay 80 so that they operate together from instrument power at circuit 75. In its deenergized position, solenoid valve 66 allows passage of controller 61 pneumatic output signals to valve 19. Correspondingly, solenoid valve 77 in its deenergized position allows passage of reset action air signals to flow from controller 61 through conduit 78, the valve and conduit 79 and back into the reset portion of the control mechanism 64. Control relay 80 has a set of normally closed contacts in circuit from instrument power at circuit 75 through circuit 81 to the second phase winding of servo-motor 63.

Hence, when there is insufficient quantity of mix, as represented for example by the absence of movement of conveyor 12 and an absence of a signal at circuit 15, or by an insufficient level of sinter mix 11 on conveyor 12 as determined by paddle switch 25, either condition of which will cause the presence or absence of a command signal on circuit 26. In the case where there is no command signal in circuit 26, solenoid valve 69 remains deenergized and causes shut off valve 24 to remain closed thus prohibiting flow of water to spray head 21. Simultaneously, in the absence of a command signal on circuit 26, time delay relay contacts remain closed, thus supplying power from circuit 75 over circuit 76 to the coils of solenoid valves 66, 77 and control relay 80, the latter three acting to hold moisture controller 61 inoperative at the control conditions that existed at the instant of the absence of signal at circuit 26. This action immobilizes servo-motor 63 even though it may be off the set point, maintains the pneumatic control signal on the operator

of valve 19 by closing off the passage of air between conduits 65 and 68, thus maintaining flow control valve 19 in its last operating position ready to permit the same flow rate of water to spray head 21 when operating conditions are restored. Moreover, the immobilizing action prevents any controller action from taking place even though there is an impedance change across probes 31 and 32 during the shutdown or operating condition which prevented the command signal from appearing on circuit 26. Condition responsive apparatus 60 operates in a similar manner as apparatus 30 in FIG. 1 insofar as its other components are concerned such as impedance detection and electronic control signal generation.

When sufficient quantity of sinter mix 11 is present, such as is indicated by the movement of the proper level of materials on conveyor 12, then the command signal will appear on circuit 26 by the closure of switch 25 which passes the signals from circuit 15. This immediately energizes solenoid valve 69 by blocking port *c* and opening ports *a–b* which opens shut-off valve 24 completely and allows a controlled amount of addition water determined by the position of valve 19 to flow from spray head 21. Simultaneously, the coil in time delay relay 74 becomes energized but its contacts close only after a preset time delay which, for example may be adjusted to correspond to material movement time from spray head 21 to probe 31, including the restoration time of servo-motor 63 to normal operation. Allowance should be made for controller 61 to make any adjustment due to a change in impedance at probes 31, 32, if such, occurred after time delay relay 74 operated. Hence, the condition-responsive apparatus 60 is restored to a closed loop mode of control operation in a rapid, smooth and precise manner while preventing a deluge of addition water at spray head 21. This prevents sinter mix 23 from being excessively moistened and becoming a highly sticky agglomerate which would result in a substantial reduction in its air permeability and sintering production capability.

Reference will now be had to FIG. 3 where there is shown an electrical schematic diagram of impedance gage 37 incorporating temperature compensator 38 and conductivity compensator 39 circuits as employed in either of the condition responsive apparatus 30 or 60 of the present invention.

Impedance gage 37 comprises an impedance bridge 100 responsive to the impedance signal developed across probe electrodes 33, 34, and consists essentially of two half bridge circuits 101 and 102 arranged in a Wheatstone type circuit. Impedance bridge 100 has a pair of input terminals 103 and 104 supplying power to each bridge half 101 and 102 from a regulated AC source 105 applied to input transformer 106. The latter device has a variable secondary winding which functions as gage sensitivity adjustment 107 by varying the amount of AC voltage applied to the input of impedance bridge 100 at its input terminals 103 and 104.

Half bridge 101 has included in one of its arms impedance device 108 serially connected with DPDT check switch 109 at the common terminal of section 109*a*. Electrodes 33–34 in impedance detecting probes 31–32, respectively, are connected through circuit conductors 35 and 36 to the "operate" terminals (Op) in check switch sections 109*a* and 109*b*, respectively. Shunted across the common terminal of each section of check switch 109 is an adjustable impedance device 110 which serves as a probe sensitivity adjustment and is varied to accommodate the impedance range of moisture treated feed mix 23 appearing across the electrodes 33–34. Impedance device 110 may be eliminated from half bridge 101 when this feature is not desired.

An adjustable dummy load impedance 111 is connected across the check (Ck) position terminal of switch section 109*a* and a comon terminal of switch section 109*b* so as to provide an equivalent impedance when no moistened feed mix material appears across electrode materials 33–34. This situation may arise when removing impedance detecting probes from the movable mass to check operation and stability of apparatus 30 or 60. The other arm of half bridge 101 consists of impedance 112 connected across common leg of switch 109*b* and input terminal 103.

Half bridge 102, opposing bridge 101, consists of an impedance device 113 serially connected between input terminal 104 and moisture range adjustment 114 which has two couter-rotating rheostats 114*a* and 114*b*, the connection from impedance 113 being to the fixed terminal of rheostat 114*b*. Fixed connection on rheostat 114*a* is directly connected to input terminal 103. The slider connection on rheostat 114*a* is connected by means of conductor 115*a* to conductivity compensating adjustment 116 which has a pair of counter-rotating rheostats 116*a* and 116*b*, the wire 115*a* being connected to the fixed terminal of rheostat 116*b*. Slider connection of rheostat 114*b* is serially connected by means of conductor 115*b* to the fixed terminal of conductivity compensating adjustment rheostat 116*a*.

In one embodiment where automatic conductivity compensation is desired, compensating adjustment 116 may be driven by a servo-motor acting in response to conductivity signals detected in the moisture deficient feed mix elsewhere in the process step. In this arrangement the chloride content, for example, in the flue dust may be predetermined as well as the electrolytic effect of the addition water applied to spray head 21. Other chemical properties effecting conductivity may, of course, be included in the overall conductivity compensating feature if processing procedures required such attention to maintain the best permeability impedance at substantially fixed values as illustrated in FIG. 5 at line 5D in order to maintain set point as close to 5C as is desired.

Alternatively, conductivity compensating adjustment 116 may be manually operated by adjusting it to predetermined positions corresponding to conductivity factors of feed mix 23. If, for example, a predetermined amount of flue dust having a known conductivity effect on the mix were caused to be manually varied for processing reasons, then compensating adjustment 116 can be varied to offset this effect by rotating it to a predetermined position corresponding to the change caused by the difference in the chloride content in the mix. Moreover, other predetermined chemical effects on conductivity may be accounted for by rotating conductivity adjustment 116 correspondingly.

Regardless of whether the conductivity adjustment is occasioned by automatic or manual means, the effect on the feed mix 23 is as shown in FIG. 5 at line 5F. Therefore, rheostats 116*a* and 116*b* are circuited in impedance gage 37 to offset the impedance error detected across probe electrodes 33 and 34, thereby maintaining essentially a constant output when the aforesaid conditions vary.

Temperature compensator 38, as previously mentioned, consists essentially of a servo-driven temperature recorder having a transmitting slide wire impedance in the form of a potentiometer circuited entirely independent of the other circuits of the instrument. This transmitting slide wire potentiometer is identified as temperature compensating adjustment 120. Its fixed electrical end connections are circuited to the sliders of conductivity compensating adjust rheostats 116*a* and 116*b* through conductors 119*a* and 119*b*. The slider connection of temperature compensating adjustment 120 is mechanically driven by two-phase servo-motor 121 from signals delivered by instrument power circuit 75 to one of its phase windings and the output from measuring and amplifying circuits 122 to the other of its windings, thus causing direction and rotation proportional to thermocouple 33*a* input signals at 122.

Thermocouple 33*a* detects the temperature of the moisture treated feed mix 23 at probe 31. It is important to signal the temperature of the impedance detected mass.

If determined elsewhere, an erroneous compensating effect on gage 37 will occur and cause controller 43 or 63 to cause the wrong amount of moisture to be added to mix 23. The output voltage from thermocouple 33*a* is connected over conductors 40*a* and 40*b* to the input of measuring and amplifying circuits 122 in temperature compensator 38. When signals increase from thermocouple 33*a*, they cause servo-motor 121 to rotate and vary adjustment 120, and vice versa. Temperature compensator 38 is circuited and calibrated to offset the temperature effects on mix impedance as illustrated in FIG. 5 at curve 5E.

As the impedance appearing across probe electrodes 33 and 34 changes due to the temperature effects on a heat treated mix, this will be offset by the action of temperature compensator 38 to maintain essentially the same output across impedance bridge 100. As the temperature increases to the vicinity of about 180° F., for example, the moisture content in the mix is subjected to some evaporation, this being in proportion to the temperature detected at thermocouple 33*a*. Temperature compensator 38 may be so calibrated to overcompensate for temperature effects on the mix so that some slight additional amount of moisture is added at spray head 21 to offset the effects of evaporation in the heated mix 23.

When processing apparatus is expansive, or where the evaporation effects are significant, or both, a separate evaporation compensating adjustment may be provided by serially connecting a pair of counter-rotating rheostats between the slider arms of rheostats 116*a* and 116*b* and temperature compensating adjust potentiometer 120 in a manner like conductivity compensating adjust 116 is circuited between moisture range adjustment 114 and temperature compensating adjustment 120. This, of course, may be manually or automatically operated according to preadjustments in the circuit for the evaporation effects on the moisture treated feed mix 23.

Impedance bridge 100 has a pair of output terminals 124 and 125. Terminal 125 is connected at a fixed midpoint in half bridge 101 between the common terminal of check switch section 109*b* and impedance 112. Output terminal 124 is connected to an adjustable midpoint in half bridge 102, this being at the slider connection of temperature compensator adjust 120 by means of conductor 123.

As an AC output signal appears across terminals 124 and 125, it is fed to the input of rectifier 126, a conventional semi-conductor device. Alternatively, the AC output signal may be fed through an optional isolating transformer (not shown) where its primary winding is connected to output terminals 124 and 125 and its secondary winding is connected to the input of rectifier 126. The DC signal delivered at the output of rectifier 126 is applied to adjustable filter 127, which consists of adjustable impedance components such as fixed resistors and variably selected shunt capacitors, and where substantial amounts of filtering of the DC signal from rectifier 126 may take place as desired.

In some applications, the filtered DC signal appearing at the output of adjustable filter 127 may be quite satisfactory for use in signaling a moisture controller such as 43 or 61 and may therefore be connected directly thereto from the output of impedance gage 37. In more precise operations, non-linearities in the impedance characteristics of mixes such as those exhibited by the returns effects and moisture effects on impedance (Curves 5A and 5B) may prove troublesome if accentuated. It may be desirable to correct the DC control signal before issuing such non-linearities and achieve even greater control system performance and better accuracy of air permeability factors.

The foregoing may be achieved by connecting the output from adjustable filter 127 to function generator 128 which includes a well-known non-linear impedance network having the proper characteristics to adjust for the non-linearities exhibited by impedance properties of Curves 5A and 5B. The utilization of a function generator 128 will improve the moisture addition accuracy because controller 43 or 61, whichever is used, is a linear responsive device, i.e., for each unit of input signal there is a corresponding proportional output signal and a linear adjustment in the throttling range of the controller due to reset action. Thus, for each unit of deviation in the input signal, the controller reset action displaces a prescribed amount on a linear basis.

However, both the moisture effect and returns effect on impedance Curves 5A and 5B being non-linear have a varying slope between the ends of the curves. This indicates that for an incremental change in either of these properties the corresponding change in impedance will be greater at the higher impedance levels than at the lower impedance levels for the moisture effects according to Curve 5A, and on a somewhat different basis for Curve 5B. For example, a ½% moisture change in the mix from 6½ to 6% would produce less incremental change in mix impedance than a ½% change from 5½ to 5%. Since controller 43 or 61 is a linear device, its reset action can be adjusted for only one rate. Hence, it could not properly accommodate a varying rate and still achieve the proper addition of water and maintain the best air permeability of the mix.

Since the controller 43 or 61 reset action operates at a uniform rate of correction instead of following a variable rate, correction for non-linearities are provided by function generator 128. The resulting air permeability will remain somewhere within the optimum range illustrated in Curves 4D and 4E in FIG. 4. The particular output from function generator 128 is applied over circuit 42 to the measuring circuits in moisture controller 43 or 61, depending upon the embodiment selected.

In operation, impedance gage 37 receives moisture treated feed mix 23 across electrodes 33 and 34 operating into half bridge 101 where its impedance is compared with the adjustable half of bridge 102. It delivers a DC millivolt signal at output circuit 42 proportional to detected impedance compensated for temperature and conductivity effects thereon by compensators 38 and 39. Without function generator 128, the output will be directly proportional to the corrected impedance and will include non-linearities as they may exist in the feed mix. When using function generator 128 the output signal will be non-linear with respect to corrected impedance, these characteristics being governed by the non-linear network of function generator 128.

When each of the major components in the measuring portion of condition-responsive apparatus 43 or 64, i.e., impedance gage 37, temperature compensator 38 and conductivity compensator 39 are each properly circuited and calibrated to respond to returns and moisture effects according to Curves 5A and 5B, and corrected for the effects of temperature and conductivity according to Curves 5E and 5F, and these effects coinciding at set point 5C where a feed mix as previously described having 40% returns, 6½ moisture, 160° F. temperature and 2500 ohms impedance representing the best air permeability for that mix, then as impedance increases, generally signifying a dry mixture as detected at the probes, the DC millivolt output at circuit 42 will decrease and act on controller 43 or 61 so as to produce a greater flow rate of moisture at spray head 21. As the impedance decreases from the set point signifying greater moisture content than desired, the millivolt output will increase, thus having the effect of reducing the flow rate at spray head 21.

With a proper impedance selection in the various components of the impedance bridge and its appended compensators to accommodate the 2500 ohm mix impedance and about 28½ volts AC applied from source 105, the DC output signal may range from zero to 30 millivolts

at circuit 42, and greater if desired by adjusting the shunted output of filter 127. This later feature scales the output voltage at circuit 42 proportional to impedance changes across probe electrodes 33–34.

Thus, it has been shown to be advantageous to control air permeability of a moisture treated mix of particulate materials through measuring and controlling its moisture content by means of detecting electrical impedance of the mix. Moisture control is obtained by varying the amount of moisture addition responsive to impedance measurements to maintain a uniform impedance level of the mix when compensated for otherwise error producing effects of temperature and conductivity on the detected impedance measurements. That by maintaining a uniform impedance of moisture treated particulate materials the best air permeability will be maintained as the amount of returns vary provided the proper amount of make-up water is added to the mix. Further, it has been shown advantageous to program the moisture addition in respect to the quantity of moisture deficient material delivered for moisture treatment, thereby maintaining a substantial uniform quality and air permeability of the mix.

While the best embodiments of the present invention have been shown and described, the invention is not to be considered as limited to the exact embodiments herein shown, but it is intended to include modifications, substitutions, and equivalents within the scope and spirit of the appended claims.

I claim:

1. Condition-responsive apparatus for controlling the air permeability of a feed mix of movable particulate materials subject to treatment by a moisture addition device, said mix having electrical impedance excursions corresponding to physical variations in processing conditions, said apparatus comprising:

impedance-responsive measuring means for producing a proportional control signal in relation to the impedance of a movable bed of feed mix detected downstream of the moisture addition device, said measuring means including compensating means for offsetting the effects on detected impedance of variations in mix temperature and the conductivity of at least one mix ingredient;

means operatively associated with the moisture addition device and responsive to the compensated control signal for adding controlled amounts of moisture to the feed mix according to predetermined requirements, thereby controlling said air permeability.

2. Condition-responsive apparatus according to claim 1 wherein the control signal decreases with an increase in impedance and operates on the moisture addition device to increase the controlled amounts of moisture added to the feed mix.

3. Condition-responsive apparatus according to claim 1 wherein the control signal operates on the moisture addition device to reduce the percentage moisture content in the feed mix as its air permeability increases.

4. Condition-responsive apparatus according to claim 1 wherein the impedance excursion are non-linear and the control signal operates on the moisture addition device to maintain the feed mix at a substantially constant impedance value.

5. Condition-responsive apparatus according to claim 1 wherein the control signal operates on the moisture addition device to control the feed mix moisture content to maintain said air permeability within an optimum range.

6. Condition-responsive apparatus according to claim 1 wherein an impedance excursion corresponds to a variation in moisture content detected in the feed mix.

7. Condition-responsive apparatus according to claim 1 wherein an impedance excursion corresponds to a variation in constituent proportions detected in the feed mix.

8. Condition-responsive apparatus according to claim 1 wherein impedance excursions correspond to variations in moisture content and constituent proportions detected in the feed mix.

9. Condition-responsive apparatus according to claim 1 wherein the impedance-responsive measuring means comprises:

probe means for detecting the electrical impedance of said mix and signaling its co-related temperature,

impedance gage means operative in dependency on the probe means for producing a control signal in proportion to the detected electrical impedance, and

compensating means receiving the probe means temperature signal and a conductivity signal for offsetting such effects on detected impedance.

10. Condition-responsive apparatus according to claim 9 wherein the probe means comprises a spaced pair of impedance detecting probes each having an operating end adapted for continuous insertion into the movable mass and including an insulated electrode circuited to the impedance gage means, at least one of said probes having temperature sensing means incorporated in its operating end and circuited to said compensating means.

11. Condition-responsive apparatus according to claim 9 wherein the impedance gage comprises an AC driven impedance bridge having a first half bridge operative in dependency on the probe means and a second half bridge operative in dependency on said compensating means for producing an AC output voltage proportional to corrected mix impedance, and means for rectifying and filtering the AC output voltage to produce said control voltage.

12. Condition-responsive apparatus according to claim 9 wherein the impedance gage includes a function generator having a non-linear network for offsetting non-linearities in control voltages issued by the filtering means.

13. Condition-responsive apparatus according to claim 1 wherein the last named means includes a controller having proportional plus reset action adapted to receive the compensated control signal and operatively associated with moisture addition device.

14. Condition-responsive apparatus according to claim 1 wherein the last named means includes a two-mode controller having components for receiving the compensated control signal and, through proportional plus reset action, issuing a modified control signal which acts on the moisture addition device, and means operatively associated with the controller and said moisture addition device for programming moisture addition to the feed mix responsive to prescribed processing conditions.

15. Condition-responsive apparatus according to claim 14 wherein the means for programming moisture addition includes means responsive to a command signal for momentarily preventing the controller's reset action from accumulating and rendering its modified control signal ineffective, and for momentarily terminating addition moisture, all during an interruption in feed mix movement, thereby preventing too much moisture from being added to the feed mix both during and momentarily after interruptions in its movement.

16. Condition-responsive apparatus according to claim 15 wherein said controller is an electro-pneumatic device and the means responsive to the command signal includes electrically operated valve means for momentary interrupting the modified control signal and addition moisture and immediately restoring them to a limited value upon movement of the feed mix, and time delay relay means for restoring the controller reset action after movement of the feed mix commences.

17. Condition-responsive apparatus for controlling the air permeability of a feed mix of movable particulate materials subject to treatment by a moisture addition device, said mix having electrical impedance excursions from a fixed value representative of said air permeability, which excursions correspond to physical variations in processing conditions, said apparatus comprising:

probe means for detecting the electrical impedance of a movable bed of feed mix downstream of the mois-

ture addition device and for signaling the co-related temperature of the detected mix,

impedance gage means operative in dependency on the probe means for producing a control signal in proportion to the detected electrical impedance,

compensating means receiving the temperature signal and a conductivity signal detected elsewhere in the feed mix for offsetting their corresponding effects on detected impedance and causing the impedance gage means to produce a compensated control signal,

two-mode controller means operatively associated with the moisture addition device and having components for receiving the compensated control signal and, through proportional plus reset action, issuing a modified control signal which acts on the moisture addition device, and

means operatively associated with the controller means and said moisture addition device for programming moisture addition to the feed mix to maintain its impedance at a constant value, thereby controlling said air permeability.

18. Condition-responsive apparatus for measuring and controlling the moisture content of a feed mix of movable particulate materials subject to treatment by a moisture addition device, said mix having electrical impedance excursions corresponding to variations in the moisture content in said feed mix, said apparatus comprising:

impedance-responsive measuring means for producing a proportional control signal in relation to the impedance of a movable bed of feed mix detected downstream of the moisture addition device, said measuring means including compensating means for offsetting the effects on detected impedance of variations in mix temperature and the conductivity of at least one mix ingredient,

means operatively associated with the moisture addition device and responsive to the compensated control signal for adding controlled amounts of moisture to the feed mix to maintain its impedance at a constant value, thereby controlling said moisture content within a predetermined percentage by weight of said feed mix.

19. Condition-responsive apparatus for measuring and controlling the moisture content of a feed mix of movable particulate maerials subject to treatment by a moisture addition device, said mix having electrical impedance excursions corresponding to variations in the moisture content in said feed mix, said apparatus comprising:

probe means for detecting the electrical impedance of a movable bed of feed mix downstream of the moisture addition device and for signaling the co-related temperature of the detected mix,

impedance gage means operative in dependency on the probe means for producing a control signal in proportion to the detected electrical impedance,

compensating means receiving the temperature signal and a conductivity signal detected elsewhere in the feed mix for offsetting their corresponding effects on detected impedance and causing the impedance gage means to produce a compensated control signal,

two-mode controller means operatively associated with the moisture addition device and having components for receiving the compensated control signal and, through proportional plus reset action, issuing a modified control signal which acts on the moisture addition device, and

means operatively associated with the controller means and said moisture addition device for programming moisture addition to the feed mix to maintain its impedance at a constant value, thereby controlling said moisture content within a predetermined percentage by weight of said feed mix.

20. Condition-responsive apparatus according to claim **19** wherein the probe means comprises a spaced pair of impedance detecting probes each having an operating end adapted for continuous insertion into the movable mass and including an insulated electrode circuited to the impedance gage means, at least one of said probes having temperature sensing means incorporated in its operating end and circuited to said compensating means.

21. Condition-responsive apparatus according to claim **19** wherein the impedance gage comprises an AC driven impedance bridge having a first half-bridge operative in dependency on the probe means and a second half-bridge operative in dependency on said compensating means for producing an AC output voltage proportional to corrected mix impedance, and means for rectifying and filtering the AC output voltage to produce said control voltage.

22. Condition-responsive apparatus according to claim **19** wherein the impedance gage includes a function generator having a non-linear network for offsetting nonlinearities in control voltages issued by the filtering means to maintain the feed mix at a substantially constant impedance value.

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