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APPARATUS FOR AND METHOD OF DETECTING TEMPERATURE CONDITIONS OF MATERIAL BEING PROCESSED IN ROTARY KILN OR THE LIKE

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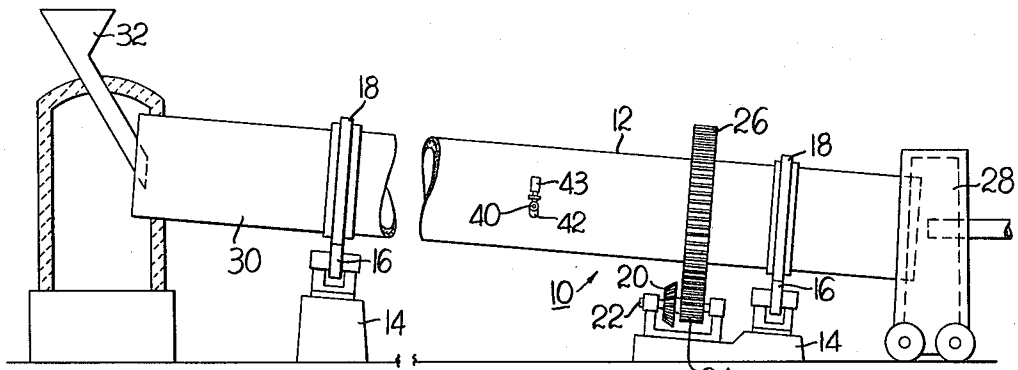

Fig.1

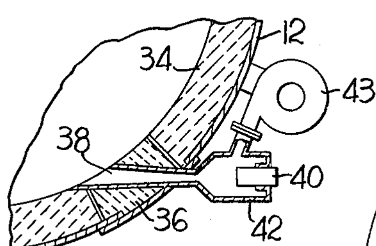

Fig.2

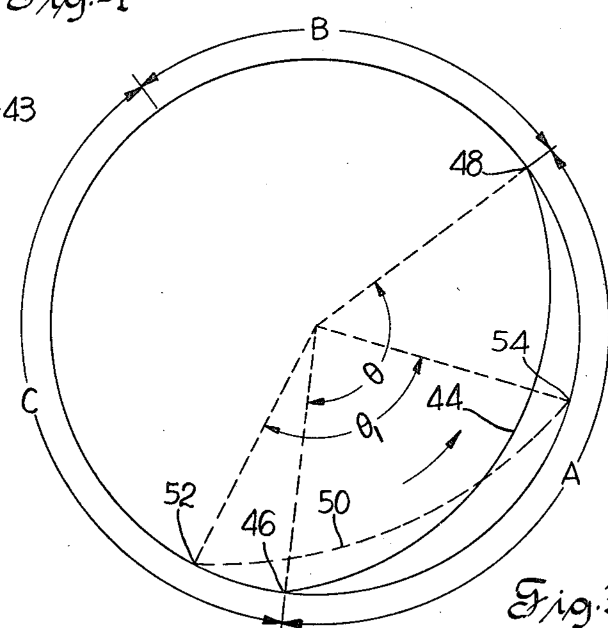

Fig.3

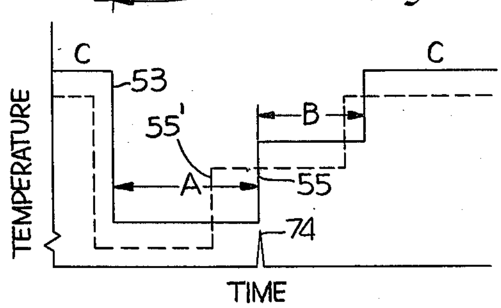

Fig.4

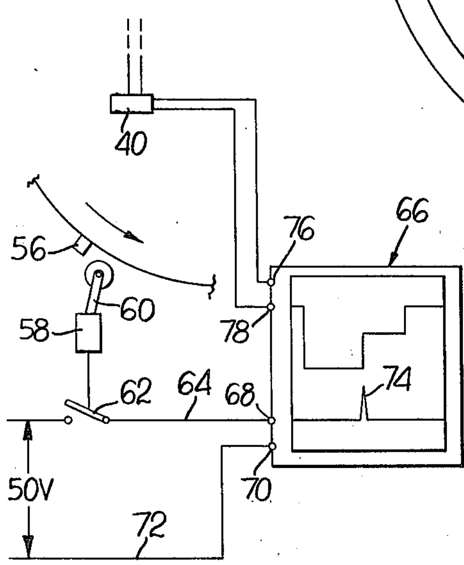

Fig.5

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APPARATUS FOR AND METHOD OF DETECTING TEMPERATURE CONDITIONS OF MATERIAL BEING PROCESSED IN ROTARY KILN OR THE LIKE

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ABSTRACT OF THE DISCLOSURE

In a rotary kiln, cementitious material leaving the calcining zone to enter the burning or clinkering zone has a different profile along the inner surface of the kiln in a plane transverse of the longitudinal axis of the kiln when at the proper temperature than when at a temperature which is too low. In accordance with the invention, a "pip" or other reference mark is automatically placed on the graph of kiln temperature at a predetermined time in each revolution of the kiln. The location of this "pip" relative to the line showing an abrupt change in temperature due to passage of a pyrometer from beneath the material is an indication of whether the material being processed has a profile corresponding to the proper temperature or a profile corresponding to a temperature which is too low. This information may be utilized to provide any necessary regulation of the kiln temperature as by adjustment of the kiln fuel supply and/or adjustment of the kiln speed.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates to temperature measurement in rotary kilns or the like, and more particularly to an apparatus for and method of indicating the temperature condition of material being processed.

Description of the prior art

In the production of cement or the like in rotary kilns, the materials to be processed into the cementitious end product are introduced into the upper or feed end of the kiln and proceed down the inclined rotating kiln through: (1) a preheating zone; (2) a calcining zone; and (3) a burning or sintering zone where the calcined product is converted into clinker. In a typical cement processing kiln, the material at the time it leaves the calcining zone and enters the burning zone should be at a temperature of approximately 1700° F. In some cases, at the time the material leaves the calcining zone, it is not at a sufficiently elevated temperature and may be at a temperature, for example, of approximately 1400° F. rather than 1700° F. When the material leaving the calcining zone is at this lower temperature, improper calcining results and the relative short length of time that the material is in the burning zone is insufficient to complete the calcining of the material, with the result that the cementitious materials never get heated to the proper temperature and are therefore improperly calcined. As a result, the end cement product is of poor quality.

One way of correcting this problem is to detect the undesirable low temperature condition of the material in the calcining zone and to slow the rotation of the kiln in response to detection of such a low temperature of material to provide more time for the material to be heated as it passes through the calcining zone. Alternatively, the fuel supply may be increased to increase the temperature in the calcining zone.

While it is known to use temperature detection devices for sensing the temperature of the material as it is about to leave the calcining zone, a problem which is sometimes

encountered is that the temperature detection devices do not provide sufficient resolution to give an entirely reliable temperature indication of the material at the time it is about to leave the calcining zone to enter the burning zone. For example, radiation pyrometers which are frequently employed to measure temperatures inside of rotary kilns have a nonlinear indicating response characteristic. Thus, for example, a radiation pyrometer measuring a kiln temperature in the range of 1400°–1700° F. has a very small output and inadequate resolutions (that is the distance between graduations for a given temperature change is small). On the other hand, such a pyrometer has much better resolution at the higher end of its measurement range such as in the range of 2500° F. For the reasons just given, available instruments for measuring temperature of the material being processed at the time it leaves the calcining zone are not as reliable as might be desired and taken alone, do not always provide a sufficiently reliable criterion upon which to base control of the kiln operation. In any event, the information as to load temperature conditions obtained by using the method and apparatus of the present invention can be used as a "back-up" or supplement to load temperature information derived in other ways.

In the calcining zone of the kiln, the material being processed in its somewhat plastic state tends to ride up along the side of the kiln in the direction of the rotation of the kiln. I have discovered that the profile of the material being processed as it lies along the kiln surface in a plane transverse of the longitudinal axis of the kiln when the material is at the normal temperature at which it should leave the calcining zone, such as 1700° F. for example, is different than the profile of the material in the same region when the temperature of the material is lower, say 1400° F. for example, such latter temperature being undesirably low for material leaving the calcining zone. As the pyrometer or other temperature measuring instrument moves from beneath the "top-of-the-load" point of the material being processed during rotation of the kiln, the temperature graph will show an abrupt temperature rise due to the fact that the temperature of the material as read under the load is substantially lower than the temperature of the radially inner surface of the load which the pyrometer measures immediately following moving from beneath the load, and the point in the rotation of the temperature measuring device or pyrometer at which this abrupt temperature rise is detected is an indication of the contour or profile of the material being processed, and hence an indication of its temperature condition.

Also, an abrupt temperature drop is measured when the temperature measuring device passes beneath the "bottom-of-the-load" point, and the point in the rotation of the temperature measuring device at which this abrupt drop occurs is also an indication of the contour or profile of the material being processed, and hence an indication of its temperature condition. However, the difference in location of the "bottom-of-the-load" point for a sufficient temperature load and an insufficient temperature load is not as significant as the difference in location of the "top-of-the-load" points for the sufficient and insufficient temperature loads, and hence it is preferred to use the "top-of-the-load" point as a reference, with the "bottom-of-the-load" point providing secondary information.

SUMMARY OF THE INVENTION

It is an object of this invention to provide an apparatus for and a method of indicating the temperature condition of material in the calcining zone of a rotary kiln as it is about to pass into the burning zone of the kiln.

It is another object of the invention to provide an apparatus for and method of indicating the temperature condition of material in the calcining zone of a rotary kiln which can be used in conjunction with the reading indicating given by a temperature measuring device such as a pyrometer or the like to provide a highly accurate indication of the temperature condition of the material in the rotary kiln.

In accordance with the invention, a "pip" or other reference mark is automatically placed on the graph of kiln temperature at a predetermined time in each revolution of the kiln. This reference mark or pip can be broadly considered as a reference signal which occurs at a given point in the rotation of the kiln on each revolution thereof. The location of this pip relative to the line showing an abrupt change in temperature due to passage of the pyrometer from beneath the material is an indication of whether the material being processed has a profile along the kiln wall corresponding to the normal higher temperature of the material (say 1700° F., for example, which it should have as it leaves the calcining zone) or whether the material has a profile corresponding to the lower temperature of the material, such as 1400° F. for example. This information derived from the relative position of the pip is itself a rather accurate indication of whether the material is sufficiently hot at the time it leaves the calcining zone and, furthermore, when taken together with the temperature graph which itself can be read in terms of temperature, provides a highly accurate indication of the temperature conditions of the material at the time it leaves the calcining zone of the kiln.

Further objects and advantages of the invention will become apparent from the following description taken in conjunction with the accompanying drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevation view, partially in section, of a rotary kiln embodying the invention;

FIG. 2 is a view in section, broken away, showing the pyrometer mounted on the kiln contiguous the junction between the calcining and burning zones of the kiln;

FIG. 3 is a view in transverse section of the rotary kiln, showing the contour or profile of material as it is about to leave the calcining zone of the kiln under the following conditions: (1) proper or sufficiently high temperature of the material being processed; and (2) insufficiently high temperature of the material being processed;

FIG. 4 is a graphical diagram showing temperature readings recorded by the pyrometer versus angle of rotation of the kiln for both sufficient and insufficient temperature conditions, and also showing the superposed pip relative to the graphs of both the sufficient and insufficient temperature conditions of the material; and

FIG. 5 is a diagrammatic view showing the connections of the pyrometer and of the pip circuit to the temperature recording device.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings and more particularly to FIG. 1, there is shown a rotary kiln generally indicated at **10** comprising a cylindrical kiln shell **12**. The kiln **10** is supported for rotation on its foundation **14** which is so constructed as to impart a slight downward inclination to the kiln from the feed end to the discharge end of the kiln. The inclination may be of the order of one-quarter inch to five-eighths inch per foot, for example, but may be any desired suitable amount. Rollers **16** mounted on foundation **14** cooperatively engage riding rings **18** mounted on the kiln shell **12** in any well known manner for rotation of the shell about the longitudinal axis of the kiln. Appropriate driving means, not shown, may actuate a bevel gear **20** fixed to the shaft **22** which carries a pinion **24** in intermeshing coacting engagement with a ring gear **26** carried by the kiln shell **12** for revolving the kiln. The lower end of the kiln is associated with a firing system **28** which may be either a coal, gas burning or other suitable type for furnishing hot gases. The upper end (the feed end) of the kiln proper is formed to receive a preheater unit **30**. The material to be heated in the kiln is supplied to the feed end of the kiln by means of a chute or hopper **32**.

As best seen in FIG. 2, the illustrated kiln has on the inside of the steel shell **12** a refractory lining **34**, which has one of several exchangeable pieces **36**, preferably of suitable ceramic material. In section **36** of the refractory lining, a sight hole **38** is provided which serves as a radiation channel for the radiation pyrometer **40** which is diagrammatically shown as being mounted on the outside of the rotary kiln in a duct **42** which is in pneumatic communication with the sight hole **38** and also in pneumatic communication with a blower **43** which is suitably mounted on the outer surface of kiln shell **12**.

Referring now to FIG. 3, there is indicated at **44** the profile of the "sufficient temperature" load contiguous the junction of the calcining and burning zones. Profile **44** subtends an angle indicated at θ and extends along the inner periphery of the kiln from point **46** to point **48**. The kiln is assumed to be rotating in a counterclockwise direction with respect to the view shown in FIG. 2. Point **46** is located approximately 170° in the direction of rotation from the uppermost point of the kiln and point **48** is located approximately 300° from the uppermost point of the kiln with respect to the direction of rotation of the kiln.

There is also shown in FIG. 3 the profile generally indicated at **50** assumed by the material having insufficient temperature (that is, for example, material having a temperature of approximately 1400° F. as it leaves the calcining zone). It will be noted that the bed of "insufficient temperature" material subtends an angle indicated at θ_1 which is less than the angle θ subtended by the "sufficient temperature" profile **44**. The "insufficient temperature" profile extends from point **52** located at approximately 150° from the top centermost position of the kiln with respect to the direction of rotation to a point **54** which is located approximately 250° from the uppermost point with respect to the direction of rotation of the kiln. It will be understood, of course, that the specific angles subtended by the respective profiles are given by way of example only. Profiles **44** and **50** are based on the assumption that the kiln speed and feed rate are the same in each case. The stickiness of the "sufficient temperature" material (profile **44**) has the effect of causing the material to cling to the refractory lining of the kiln. On the other hand, when the material is of insufficient temperature, the material slumps down and tends to get deeper thereby causing the profile **50** of the "insufficient temperature" material to subtend an angle substantially less than the angle subtended by the "sufficient temperature" material. A reference point with respect to the top of the load is more sensitive to changes in material consistency and hence the uppermost point **48** of the "sufficient temperature" material profile is substantially higher than the uppermost point **54** of the "insufficient temperature" profile.

The beginning or "bottom-of-the-load" point **52** of the "insufficient temperature" profile **50** is reached by the pyrometer rotating with the kiln an angular distance in advance of the beginning point **46** of the "sufficient temperature" profile **44**, although the angular spacing between points **52** and **46** is not as large or as significant as the angular spacing between the "top-of-the-load" points **48** and **54**.

Referring now to the temperature diagram shown in FIG. 4 and considering the temperature readings taken when the pyrometer is in the following three positions: (1) when the pyrometer is moving through the arc indicated as A in FIG. 3, in which the radiation pyrometer **40** is passing under the load of material being processed; (2) when the pyrometer is moving through the arc designated as B in FIG. 3, in which the pyrometer is reading the radially inner surface temperature of the material being heated; and (3) when the pyrometer is moving through the arc indicated at C in FIG. 3, in which the pyrometer is reading the opposite inside kiln wall temperature. A typical temperature when the pyrometer is in the region A is 1600° F.; a typical temperature when the pyrometer is in the region B is 2100° F. and a typical temperature when the pyrometer is in the region C is 2400° F. It can be seen, therefore, that as the pyrometer rotates and passes from the region C, in which the pyrometer is measuring the opposite inside wall temperature into the region A where it is passing beneath the material being heated, that there is an abrupt transition in the temperature reading of the pyrometer as indicated by the line **53** on FIG. 4 which represents the temperature drop from the region C (2400° F.) to the region A (1600° F.). Also when the pyrometer passes from the region A to the region B, there is an abrupt rise in temperature from the region A (1600° F.) to the region B (2100° F.) as shown by the line **55**. In the diagram of FIG. 3, the regions A, B, C have been identified with respect to a load of material having "sufficient temperature." However, it will be understood that the spans of the respective regions A, B, C would be correspondingly changed for a load of material having the "insufficient temperature" profile **50**.

In accordance with the apparatus and preferred method of the invention, the location of the abrupt temperature rise from the level A to the level B on FIG. 3 is positively correlated with the relative rotary position of the kiln so that it can be determined whether the abrupt change indicated by line **55** occurs at the point **54** of the "insufficient temperature" profile or at the point **48** of the "sufficient temperature" profile, thereby indicating whether the material is at the proper temperature as it is about to leave the calcining zone to enter the burning zone.

In order to positively orient the abrupt temperature change line **55** with respect to the kiln rotation, as just described, a cooperating limit switch and limit switch actuating element, one of which is mounted on the rotating kiln, and the other of which is stationary, are provided. Thus, as shown in the view of FIG. 5, an abutment or switch actuator element **56** is mounted on and rotates with the rotating kiln and a limit switch generally indicated at **58** including a normally open contact **62** is mounted on a stationary point adjacent the path of rotation of switch actuator element **56**, so that once in each revolution of the kiln, the actuator element **56** mounted on the kiln will actuate the arm **60** which forms part of the switch mechanism **58** to thereby close contact **62** of switch **58** momentarily. As seen in the view of FIG. 5, the normally open switch contact **62** of switch **58** is connected in series with the line **64** to the input terminal **68** of the temperature recording device generally indicated at **66**. The other input terminal **70** is connected by conductor **72** to the opposite side of the direct current power source which may be, for example, a fifty volt source. Pyrometer **40** is connected to input terminals **76** and **78** of the temperature recording device. When the normally open contact **62** is momentarily closed by actuation of the switch operating arm **60** by abutment **56** on the rotary kiln, a pip **74** appears on the recording chart, this pip indicating the relative location at the given instant of the actuator element **56** which is fixed to the kiln, and thus also giving the relative location at the given instant of the pyrometer **40** which is fixed to and rotates with the kiln. For example, the position of the abutment **56** on the kiln may be so related to the position of the pyrometer on the kiln that as the abutment **56** strikes the arm **60** of switch **58** to cause the pip **74**, the pyrometer will be passing point **48**, at which point the "sufficient temperature" profile **44** would normally be ending, in which case the location of the pip **74** would coincide with the abrupt temperature rise line **55** of FIG. 4. For purposes of illustration, it is assumed that the actuation of switch **58** to cause pip **74** occurs at the same instant that pyrometer **40** passes point **48**.

On the other hand, if the temperature of the material is too low, say 1400° F., the material will have the contour indicated at **50** in FIG. 2 in which case the pyrometer will reach the end of the contour **50** at point **54** so that in this second case the abrupt temperature rise indicated by line **55'**, on FIG. 4 would have occurred some significant angle in advance of the location of the pip, assuming that the pip is timed to coincide with the temperature rise line **55** of the "sufficient temperature" load. Thus in the second case, in which the load has an "insufficient temperature" profile **50**, the temperature rise line **55'** precedes the location of the pip **74** whereas in the first case, where the sufficient temperature profile **44** is present, the pip **74** will substantially coincide with the abrupt temperature rise line **55**.

From the location of the temperature rise line **55** or **55'** relative to the location of pip **74**, as seen on the temperature control chart, it can be determined readily whether the material being processed has a profile corresponding to the "sufficient temperature" profile **44** or whether, alternatively, the temperature of the material being processed in the calcining zone is colder than it should be and has, for example, a temperature of approximately 1400° F., in which case the contour of the material would be similar to or approach the "insufficient temperature" profile or contour indicated at **50**. The temperature of the material as indicated on portion A of the temperature chart may also be used as a corroborating indication.

As previously explained, while the reading of the pyrometer as it passes beneath the load in the kiln is of some value as an indication of the temperature of the material, the pyrometer as a general rule is not sufficiently sensitive in the temperature ranges of the readings in region A to provide an entirely reliable criterion in itself as to the temperature of the material for use as a basis for controlling the kiln operation. The location of the temperature drop line **55** or **55'** as the case may be, relative to the pip provides an accurate indication of the load profile, that is, whether the load has the "sufficient temperature" profile corresponding to line **44** or the "insufficient temperature" profile corresponding to line **50**. This information as to the profile of the material being processed while passing through the calcining zone, taken together with the temperature reading in the region A, provides an accurate basis on which to control the operation of the kiln, including adjustment of the rotary speed of the kiln and/or adjustment of the fuel supply to the kiln, as well as providing an alarm notification to the process operator when needed. Due to the significant angular difference between the top-of-the-load points **48** and **54** of the "sufficient temperature" and "insufficient temperature" loads, respectively, it is preferred to use these points as the references in conjunction with the "pip" signal upon which to base a determination of the sufficient or insufficient temperature conditions of the load. However, the "bottom-of-the-load" points **46** and **52** relative to the "pip" signal may be used in a similar manner to provide either primary or secondary information as to the temperature condition of the load.

In the example cited, the position of limit switch **58** along the path of movement of rotary kiln was such as to cause the pip to lie in a line substantially coincident with temperature rise line **55** of the "sufficient temperature" load. However, it is not important that the pip line be so located since the pip line may be located elsewhere, it merely being necessary to know where the "sufficent temperature" line **55** should lie relative to the pip line as compared to the location of the temperature rise line **55'** of the "insufficient temperature" load.

In the illustrated embodiment, the temperature readings of the temperature sensing device, and also the reference "pip" are shown as being displayed on a temperature recording chart, to define one form of presentation of the temperature readings and of the reference "pip" signal. However, this information could also be displayed in other ways, as for example, on the screen of a cathode ray oscillograph, to thereby define another form of presentation of the information. Also, the temperature readings of the pyrometer or the like and the reference "pip" signal could be fed to a digital computer, to define still another form of presentation of the temperature readings and of the reference signal. The digital computer would be programmed to perform calculations on temperature signal information to determine the position of the abrupt change in temperature at the "top-of-the-load" with respect to the reference "pip" signal. The computer may provide either an alarm notification to the process operator, or may directly perform control changes in the process, such as slowing down kiln speed, or increasing fuel supply to the kiln.

While there has been shown and described a particular embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention and, therefore, it is amied to cover all such changes and modifications as fall within the true spirit and scope of the invention.

The embodiment of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. The method of obtaining an indication of the temperature condition of material being processed in a rotary kiln in which the location of a limiting boundary of the material in a rotary direction is related to the temperature condition of the material, and in which a temperature sensing device is mounted on and rotatable with the kiln through a plurality of temperature regions including a load temperature region, which comprises the steps of: (1) obtaining from said sensing device an indication of the abrupt change in temperature sensed by said sensing device in passing said boundary: (2) providing a reference signal at a given point in the rotation of said kiln; and (3) providing a presentation of said indication of the abrupt change in temperature and of said reference signal in time relation to each other, whereby to provide an indication of the location of said limiting boundary and thereby an indication of the temperature condition of the material.

2. The method defined in claim **1** in which the load of material lying in the kiln includes a "top-of-the-load" point which defines the upper boundary of said load temperature region, and said method includes the steps of obtaining from said sensing device an indication of the abrupt change in temperature sensed by said sensing device in passing said upper boundary, and of providing a presentation of the indication of said abrupt change in temperature and of said reference signal in time relation to each other.

3. The method defined in claim **1** in which means rotated in accordance with the rotation of said kiln is effective to cause said reference signal.

4. The method of obtaining an indication of the temperature condition of material being processed in a rotary kiln in which the profile of the material transverse of the longitudinal axis of the kiln is related to the temperature of the material and in which a temperature sensing device is mounted on and rotatable with the kiln through a plurality of temperature regions including an "under-the-load" temperature region, which comprises the steps of: (1) detecting the abrupt change in temperature sensed by said temperature sensing device upon passing the boundary between said "under-the-load" temperature region and a temperature region contiguous thereto; (2) providing a reference signal at a given point in the rotation of said kiln; and (3) comparing the time relation of said abrupt change in temperature to said reference signal by visually displaying the output signal of the temperature sensing device and said reference signal as a function of kiln rotation, whereby the time relation of said abrupt change in temperature to said reference signal may be visually observed.

5. The method of obtaining an indication of the temperature condition of material being processed in a rotary kiln in which the material assumes a first profile transverse of the longitudinal axis of the kiln when the temperature thereof is sufficient and a second profile transverse of the longitudinal axis of the kiln when the temperature thereof is insufficient, in which each profile is bounded in a given rotary direction by a corresponding limiting boundary whose location is related to the temperature of the material, and in which a temperature sensing device is mounted on and rotatable with the kiln through a plurality of temperature regions including a load temperature region, which comprises the steps of: (1) obtaining from said sensing device an indication of the abrupt change in temperature sensed by said sensing device in passing a limiting boundary; (2) providing a reference signal at a given point in the rotation of said kiln; and (3) providing a presentation of said indication of the abrupt change in temperature and of said reference signal in time relation to each other, whereby to provide an indication of the location of said limiting boundary and thereby an indication of the temperature condition of the material.

6. The method defined in claim **5** in which means rotated in accordance with the rotation of said kiln is effective to cause said reference signal.

7. The method defined in claim **5** in which the load of material lying in the kiln includes a "top-of-the-load" point which defines the upper boundary of said load temperature region, and said method includes the steps of obtaining from said sensing device an indication of the abrupt change in temperature sensed by said sensing device in passing said upper boundary, and of providing a presentation of the indication of said abrupt change in temperature and of said reference signal in time relation to each other.

8. The method of obtaining an indication of the temperature condition of material being processed in a rotary kiln in which the material assumes a first profile transverse of the longitudinal axis of the kiln when the temperature thereof is sufficient and a second profile transverse of the longitudinal axis of the kiln when the temperature thereof is insufficient, and in which a temperature sensing device is mounted on and rotatable with the kiln through a plurality of temperature regions including an "under-the-load" temperature region, which comprises the steps of: (1) detecting the abrupt change in temperature sensed by said temperature sensing device upon passing the boundary between said "under-the-load" temperature region and a temperature region contiguous thereto; (2) providing a reference signal at a given point in the rotation of said kiln; and (3) comparing the time relation of said abrupt change in temperature to said reference signal by visually displaying the output signal of the temperature sensing device and said reference signal as a function of kiln rotation, whereby the time relation of said abrupt change in temperature to said reference signal may be visually observed.

9. In combination, a rotary kiln for heating load materials therein and in which the profile of the material transverse of the longitudinal axis of the kiln is related to the temperature of the material, temperature sensing means mounted on and rotatable with said kiln through a plurality of temperature regions including a load temperature region, said temperature sensing means being effective to provide an indication of an abrupt change in temperature in passing the boundary between said load temperature region and a temperature region contiguous thereto, means for providing a reference signal at a given point in the rotation of said kiln, and means for providing a presentation of said indication of the abrupt change in temperature and of said reference signal in time relation to each other, whereby to provide an indication of the location of said boundary and thereby an indication of the temperature condition of the material.

10. The combination defined in claim **9** including display means for visually displaying the output signal of said temperature sensing means and said reference signal, and means connecting said output signal and said reference signal to said display means, whereby the time relation of said abrupt change in temperature to said reference signal may be visually observed.

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