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(72) Inventor: **Paulson, Christopher**
Livermore, CA California 94550 (US)

(74) Representative: **Lord, Michael**
Gill Jennings & Every LLP
The Broadgate Tower
20 Primrose Street
London EC2A 2ES (GB)

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(71) Applicant: **Palo Alto Research Center
Incorporated**
Palo Alto, California 94304 (US)

(54) **Low-cost measurement system for photopolymer film polymerization monitoring**

(57) A monitoring device includes a light source, an optical filter, and an optical detector. The monitoring device may monitor curing processes, such as ultraviolet (UV) curing processes to determine the progression of the level of cure of a light-activated material to a substrate. The light source emits light toward a light-activated

material, such as a film, and/or a substrate. The optical filter is positioned so that a wavelength of the light is transmitted through the optical filter after the light is reflected off of the substrate and/or the film. The optical detector is positioned to detect the light that is transmitted through the optical filter.

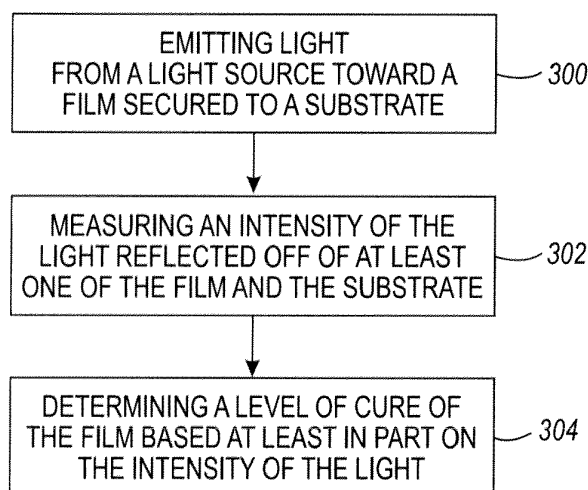


FIG. 3

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Description

BACKGROUND

[0001] Light curing processes have become very popular and useful in a wide variety of applications including printing, coating, adhesives, and the like. Many types of curing processes exist such as arc lamp and ultraviolet light-emitting diode (LED) curing processes. These curing processes alter the chemical and physical properties and structures of a light-activated material so that the material becomes "cured" to a substrate through the curing process.

[0002] One critical aspect of the light-curing process is to determine when a light-activated material has completed or is nearing completion of the curing process. An indication of completion of the curing process is to measure the extent of polymerization of the light-activated material. This determination is typically performed by Fourier transform infrared (FTIR) spectroscopy methods, which require equipment that is expensive to manufacture and maintain. Alternatively, rub or tape tests are used to determine whether the curing process is complete, which are rudimentary and subjective tests and thus require significant amounts of training the testers to perform the tests correctly and reach an accurate test result. Both the FTIR spectroscopy and the rub and tape tests are performed after the curing process has been estimated to be completed and are not done in real-time. Because the curing process is stopped to perform these tests, the overall process takes more time to complete, which reduces efficiency. Further, the rub and tape tests are very rudimentary tests that can be subjective and inefficient, which leaves room for error and a reduction in productivity.

[0003] Accordingly, there remains a need for an improved monitoring device that can detect the level of cure of light-activated materials in an accurate and cost-effective manner.

SUMMARY

[0004] A measurement device has a light source, an optical filter, and an optical detector. The light source emits light and the optical filter is positioned so that a wavelength of the light is transmitted through the optical filter after the light is reflected off of at least one of a substrate and a film cured to the substrate. The optical detector is positioned to detect the light that is transmitted through the optical filter.

[0005] A method includes emitting light from a light source toward a film cured on a substrate, measuring an intensity of the light that is reflected off of at least one of the film and the substrate and determining a level of cure of the film based at least in part on the intensity of the light. The light is emitted toward the film and substrate at an angle between 0° and 20° with respect to an axis normal to the film and the substrate.

[0006] A measurement system includes an infrared light source that emits infrared light, a substrate that includes a light-activated resin film, an optical filter that is positioned to receive the infrared light that is reflected off of the substrate and/or the film, and an optical detector that is positioned to detect the infrared light that is received by the optical filter. The infrared light is emitted onto the substrate at an angle with respect to an axis that is normal to the substrate. The film and the substrate reflect at least a portion of the infrared light that is emitted by the infrared light source.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Figure 1 shows a monitoring device in accordance with some aspects of the disclosure.

[0008] Figure 2 shows another embodiment of a monitoring device in accordance with aspects of the disclosure.

[0009] Figure 3 shows a method of monitoring a level of cure of a film attached to a substrate.

[0010] Figure 4 shows an example of a monitoring device embodied in a sensor and attached to a light-curing device.

DETAILED DESCRIPTION

[0011] With the growing popularity of light-curing devices involved in curing processes, specifically ink curing processes, the ability to monitor whether the cure is complete or at what level of cure the light-activated resin is without disrupting the curing process has become a very useful and almost critical tool. The current technologies used to monitor the curing process are either very expensive, such as the FTIR spectrophotometer, or are rudimentary and subjective, such as the tape and rub tests. None of the currently available monitoring options has the ability to provide low-cost, accurate, real-time monitoring capabilities without disrupting the curing process.

[0012] Figure 1 shows an example monitoring device 100 that includes a light source 102, an optical filter 104, and an optical detector 106 that provides low-cost, accurate, real-time monitoring of the curing processes. The light source emits light toward a substrate 108 to which a film 110 is attached or cured. The light reflected off of the substrate 108 and off of the ink film 110 is received through the optical filter 104 and is detected by the optical detector 106. The optical filter 104 can be coaxial with the optical detector 106 to prevent extra reflections in the system.

[0013] The monitoring device 100 shown in Figure 1 may be included in any suitable environment including being embodied in a sensor attached to or otherwise electrically coupled to a light-curing device that emits the light that causes the curing of the film to occur. The monitoring device 100 helps to monitor the level of cure of any light-activated material, including light-activated resins, and can be positioned anywhere with respect to the material

being cured so that the monitoring device 100 can effectively monitor the level of cure of the light-activated material(s). For example, the light activated material(s) can include ultraviolet (UV) light-activated photo-polymerizable and cross-linkable materials. The monitoring device 100 itself does not cause the light-activated material to cure, but may be included in a larger system or device that does control the curing of the light-activated material in some examples. In other examples, the monitoring device may be a separate element from the light-curing device or system.

[0014] The light source 102 of the monitoring device 100 shown in Figure 1 is any suitable light source that emits continuous or modulated light toward the film 110 and substrate 108 combination such that the light reflected off of the film 110 and substrate 108 indicates a level of cure of the film 110 or other light-activated material on the substrate 108. To determine the level of cure of the film 110, the level of relative concentration of monomers and oligomers in the film 110 may be measured. The level of cure is directly related to the concentration of the polymerization of the monomers and oligomers in the film 110. As this polymerization occurs, the number of vibrational absorptions modes of the film 110 decreases, which leads to an increase in transmission of light in the infrared region. In some examples, the range within which the reduction in absorption is best seen is light having a wavelength between 6 μm and 12 μm .

[0015] By measuring the intensity of the light reflected off of the film and/or substrate, the relative concentration of free monomers and oligomers remaining in the film can be measured. Depending on the type of substrate, as the curing process progresses, the amount of light either reflected off of or transmitted through the film and substrate increases. Figure 1 shows a monitoring device 100 in which the substrate 108 is absorptive and thus the light emitted toward the film 110 and substrate 108 is either reflected off of one or both of the film 110 and substrate 108 or is absorbed by the substrate 108. Figure 2 shows another embodiment of a monitoring device 200 in which the substrate 202 is emissive and thus light is either absorbed by the film 204 and/or substrate 202 or is transmitted through the substrate 202.

[0016] The substrate is any suitable substrate, including quartz, paper, plastic, and the like. The substrate is typically considered either emissive, reflective, or transmissive. Emissive substrates absorb light. As discussed above, the monitoring device 100 shown in Figure 1 emits light toward a reflective substrate 108 and the monitoring device 200 shown in Figure 2 emits light toward a translucent substrate 202.

[0017] The light-activated material undergoing the curing process is any suitable light-activated material that may be used to cure ink in printing processes, cure coatings on various materials such as wood, metals, and plastics, cure adhesives used to adhere two elements together, and the like. The light-activated material may be a light-activated resin that cures and quickly hardens when

exposed to certain wavelengths of light, such as ultraviolet light. In another example, the light-activated material is an ink or a film that is applied to a substrate, such as paper or plastic. When light, such as ultraviolet light, is emitted toward the substrate with such a light-activated ink or film, the ink or film becomes "cured" or otherwise hardened or dried.

[0018] As discussed above, the monitoring device includes an optical filter and an optical detector. The optical filter is positioned so that a wavelength of the light is transmitted through the optical filter after the light is reflected off of or transmitted through the substrate and/or the film. The optical filter may receive a particular wavelength or range of wavelengths of light that is reflected off of or transmitted through the substrate and/or the film in some examples. For example, the optical filter includes a bandpass filter that only permits a predetermined range of wavelengths of light to be transmitted through the optical filter and toward the optical detector. In some examples, the range of wavelengths may be 6-12 μm . In other examples, the optical filter may receive all wavelengths of light that are reflected off of the substrate and/or film.

[0019] The optical filter directs the reflected light toward the optical detector. The optical detector is any suitable detector that is capable of detecting the intensity of the light that is transmitted through the optical filter. In some examples, the optical detector includes a low-cost infrared detector when the light reflected off of the substrate and/or film includes light having a wavelength in the infrared range. For example, the optical detector is a thermopile that converts thermal energy into electrical energy by detecting an intensity of light and translating that intensity of light into a respective voltage output.

[0020] Referring again to Figure 1, the monitoring device 100 has an infrared (IR) light source 102, an optical filter 104, and an optical detector 106. As shown in Figure 1, the IR light source 102 emits light toward a film 110 that is attached or cured to a substrate 108. In this example, the film 110 is an ink and the substrate 108 is paper. While reference is made to the ink or more generally the film being "attached" to the paper or more generally the substrate, the term "attached" refers to the ink being placed on the paper prior to and throughout the curing process. As curing progresses, the ink becomes hardened and dried and thus becomes "cured" to the paper. However, the term "attached" is meant to include any positioning of the ink and the paper together throughout the curing process.

[0021] As shown in Figure 1, the IR light source 102 emits light toward the ink 110 and substrate 108 at an angle. The angle at which the IR light source 102 emits light may vary. For example, the IR light source 102 emits light toward the substrate 108 and ink 110 at an angle of approximately 10° with respect to an axis 112 normal to the substrate 108 and the ink 110. The angle may be greater than or less than 10° , but may not be exactly or approximately 90° with respect to the axis 112 normal to the substrate 108 and film 110. When the IR

light source 102 (or any other light source) emits light toward the substrate 108 and film 110 at a 90° angle, the light is directly reflected back toward the IR light source 102 at the complementary 90° angle and the light cannot be easily measured. For example, the angle at which the light is emitted toward the film 110 and the substrate 108 may be between 0° and 45° in some examples and between 0° and 20° in other examples with respect to the axis 112 that is normal to the film 110 and the substrate 108.

[0022] As shown by the arrows in Figure 1, the light emitted from the IR light source 102 is emitted toward the ink film 110 and the substrate 108. A portion of the light is transmitted through the ink film 110 and contacts the substrate 108. Some of the light contacting the substrate 108 is absorbed into the substrate 108. However, the majority of the light that contacts the substrate 108 in Figure 1 is reflected off of the substrate and is again transmitted through the ink film 110, as indicated by the arrows. Because some of the light is reflected off of the ink film 110 and some of the light is reflected off of the substrate 108, an ink film-substrate boundary 114 and an air-ink film boundary 116 are created at which the light is reflected. The increasing intensity of the reflected light is a result of the ink film 110 becoming more transparent as the curing process progresses, which permits more light to be transmitted through the ink film 110 to the substrate 108 and then reflected off of the substrate 108 at the ink film-substrate boundary 114. As the curing process progresses the portion of the emitted light that is reflected off of the ink film 110 decreases and the portion of the emitted light that is reflected off of the substrate 108 increases.

[0023] The angle at which the light is reflected off of the ink film 110 and the substrate 108 depends on the angle at which it is emitted toward the ink film 110 and the substrate 108. For example, the IR light source 102 in Figure 1 emits light toward the ink film 110 and the substrate 108 at an angle of approximately 10° and the light that is reflected off of the ink film 110 at the air-ink film boundary 116 and the light that is reflected off of the substrate 108 at the ink film-substrate boundary 114 is reflected off of the respective boundaries at an angle of 10° as well. The angle of reflection will correspond to the angle at which the light is emitted toward the ink film 110 and substrate 108.

[0024] The optical filter 104 of the monitoring device 100 shown in Figure 1 is positioned so that the light that is reflected off of the ink film 110 and the substrate 108 is received through the optical filter 104. In this example configuration, the light source 102, the optical filter 104, and the optical detector 106 are positioned on the same side of the ink film 110 and substrate 108 (*cf.* Figure 2 in which the light source is on the opposite side of the ink film and substrate from the optical filter and the optical detector, which is discussed below). The optical filter receives the light reflected off of the ink film and substrate and the optical detector is able to detect the light trans-

mitted through the optical detector. In this example, the optical detector includes a thermopile that translates the detected intensity of the light into a corresponding voltage.

[0025] Figure 2 shows an alternative embodiment of the monitoring device 200 in which the substrate 202 is a transmissive substrate, such as quartz. The function of the monitoring device 200 shown in Figure 2 is similar in nature to the monitoring device 100 shown in Figure 1, with the exception that the optical filter 206 and the optical detector 208 are positioned on opposite sides of the ink film 204 and substrate 202 from the IR light source 210. However, the monitoring device 200 shown in Figure 2 measures the intensity of the light in the same manner as the monitoring device 200 shown in Figure 1. For example, the IR light source 210 of Figure 2 emits light toward the ink film 204 and the substrate 202. A portion of the light is absorbed by the ink film 204 and a portion of the light is transmitted through the ink film 204 and through the substrate 202. In this example, the substrate 202 is considered emissive, which means that light will pass through the substrate 202 and continue its path on the opposite side of the substrate 202 from the IR light source 210, as indicated by the arrows in Figure 2. The optical filter 206 and the optical detector 208 are positioned on the opposite side of the substrate 202 from the IR light source 210 in the monitoring device 200 shown in Figure 2. As the curing process progresses, the ink film 204 becomes increasingly transparent, which allows for an increasing intensity of light to be transmitted through to the substrate 202 and thus the opposite side of the substrate 202 from the IR light source 210 so that it can be received by the optical filter 206 and detected by the optical detector 208.

[0026] Figure 3 shows various steps in a method of monitoring the curing level of a light-activated material. For example, light is emitted from a light source toward a light-activated material, such as an ink or other type of film, which is attached to a substrate 300. Then, the intensity of the light that is reflected off of one or both of the film and the substrate is measured 302. A level of cure of the film is determined based at least in part on the intensity of the measured light 304. Other steps may be optionally included in this process.

[0027] Figure 4 shows a system in which a light-curing device 400 includes a sensor 402 attached to it. The light-curing device 400 emits light, in some examples ultraviolet light, toward the film 404 and substrate 406. In this example, the sensor 402 includes a monitoring device that monitors the level of cure of the film as the curing process progresses. The monitoring device is any of the examples described above and includes an IR light source that also emits light toward the film and substrate to determine the level of cure based on the intensity of the light that is reflected off of the film 404 and the substrate 406. In some examples, the sensor 402 can be approximately 2mm x 4mm, although it can be any suitable size and shape.

Claims

1. A monitoring device, comprising:
 - a light source that emits light;
 - an optical filter positioned so that a wavelength of the light is transmitted through the optical filter after the light is reflected off of at least one of a substrate and a film cured to the substrate; and
 - an optical detector positioned to detect the light that is transmitted through the optical filter.
2. The monitoring device of claim 1, wherein the optical filter is a bandpass optical filter.
3. The monitoring device of claim 1 or claim 2, wherein the light source is an infrared light source, preferably the wavelength of the light is within a range of 6 micrometers to 12 micrometers.
4. The monitoring device of any of the preceding claims, wherein the film includes a light-activated resin.
5. The monitoring device of claim 4, wherein the light-activated resin includes an ultraviolet light activated photo-polymerizable and cross-linkable material.
6. The monitoring device of any of the preceding claims, wherein the film is an ink film and preferably wherein the ink film is light-activated with ultraviolet light.
7. The monitoring device of any of the preceding claims, wherein the at least one of the substrate and the film include a first surface and an opposing second surface, and wherein the light source, the optical filter, and the optical detector are positioned spaced apart from the first surface.
8. The monitoring device of the preceding claims, wherein the at least one of the substrate and the film include a first surface and an opposing second surface, and wherein the light source is positioned spaced apart from the first surface and the optical filter and the optical detector are positioned spaced apart from the second surface.
9. The monitoring device of any of the preceding claims, wherein the light source emits light at an angle between 0° and 45°, preferably at an angle of 10°, with respect to an axis normal to the substrate and the film.
10. The monitoring device of claim 9, wherein the optical filter and the optical detector are positioned at an angle between 0° and 45°, preferably 10°, with respect to an axis normal to the substrate and the film.

11. A method, comprising:

emitting light from a light source toward a film attached to a substrate at an angle between 0° and 20° with respect to an axis normal to the film and the substrate;
 measuring an intensity of the light reflected off of at least one of the film and the substrate; and
 determining a level of cure of the film based at least in part on the intensity of the light.

12. The method of claim 11, wherein the step of measuring the intensity includes receiving the light through an optical filter and detecting the light by an optical detector after the light is received through the optical filter.

13. The method of claim 11 or claim 12, wherein the film includes a light-activated resin.

14. The method of any of claims 11 to 13, wherein the light source is positioned on a first side of the substrate and the reflected light is measured from the first side of the substrate.

15. A monitoring system, comprising:

an infrared light source that emits infrared light;
 a substrate including a light-activated resin film positioned to receive the infrared light at an angle with respect to an axis that is normal to the substrate and that reflects at least a portion of the infrared light off of at least one of the substrate and the film;
 an optical filter positioned to receive the infrared light reflected off of the at least one of the substrate and the film; and
 an optical detector positioned such that the infrared light received by the optical filter is detected by the optical detector.

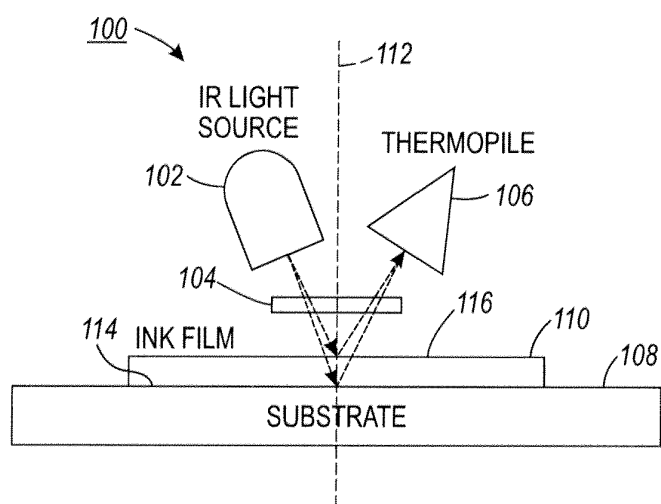


FIG. 1

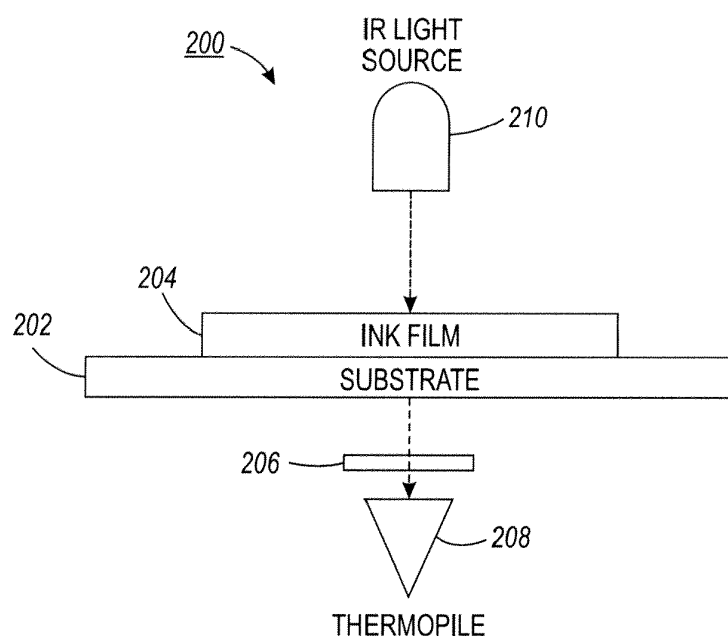


FIG. 2

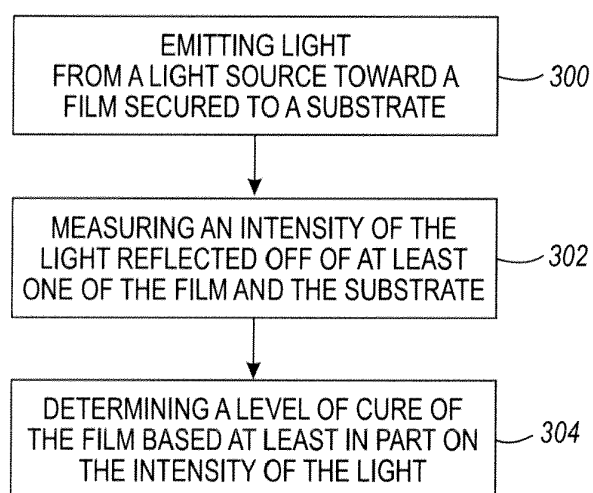


FIG. 3

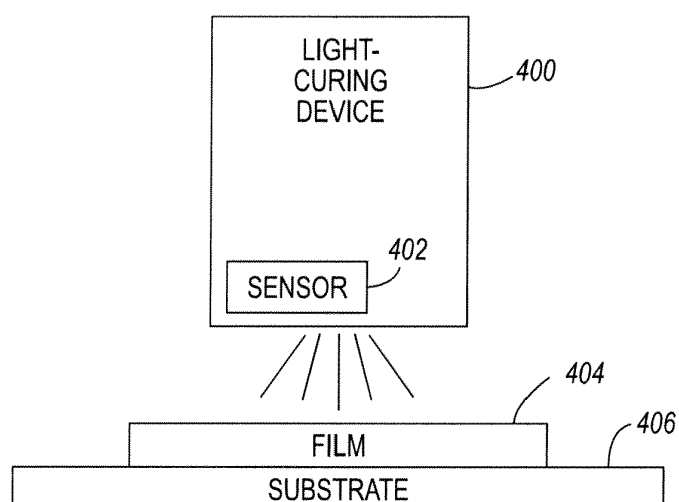


FIG. 4

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(71) Applicant
Services Pétroliers Schlumberger

(Incorporated in France)

42 rue Saint Dominique, 75007 Paris, France

(72) Inventors
Peter Vivian Coveney
Philip Fletcher

(74) Agent and/or Address for Service
Martin Hyden
Schlumberger Cambridge Research Limited,
PO Box 153, Cambridge, CB3 0HG, United Kingdom

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US 4648264 A

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INT CL⁵ **G01N**
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(54) **Method for predicting thickening times of cement slurries**

(57) A method of predicting the thickening time of a cement slurry comprising measuring or determining other properties of slurry compositions and obtaining a predicted value of the desired property by applying values representative of the other properties to a model formed by determining the other properties for a series of cement compositions and correlating these with measured values of the desired property. In one embodiment the method comprises measuring and determining the other properties and inputting values corresponding to said properties to a neural network device configured to output a value representative of the desired property, the neural network device being a) configured to utilise each of said values as input values, b) provided with at least one hidden layer of at least one node, and c) trained with a dataset comprising series of values of said properties and a value corresponding to the desired property when measured for a slurry having the measured properties. The properties measured include percentages of constituents, surface area, loss on ignition insoluble residue, temperature and pressure.

100000

Layer 1 $1/2$ Neuron j in layer 2

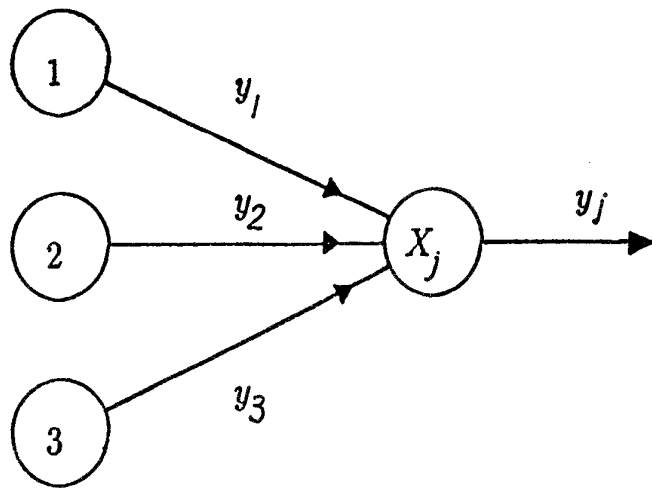


FIG.1

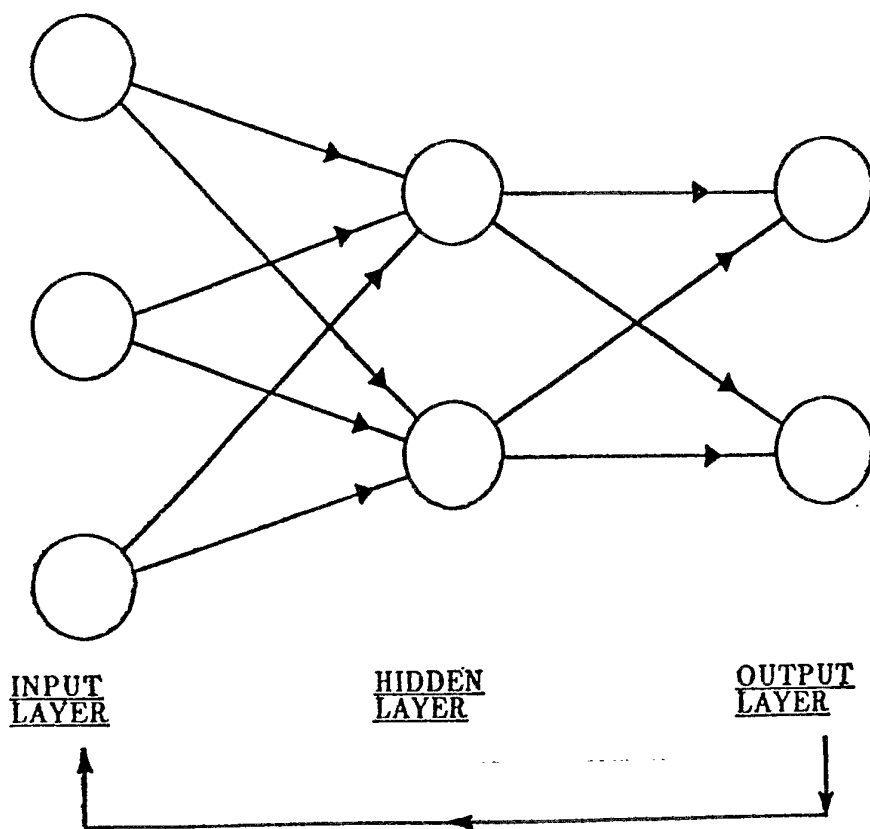
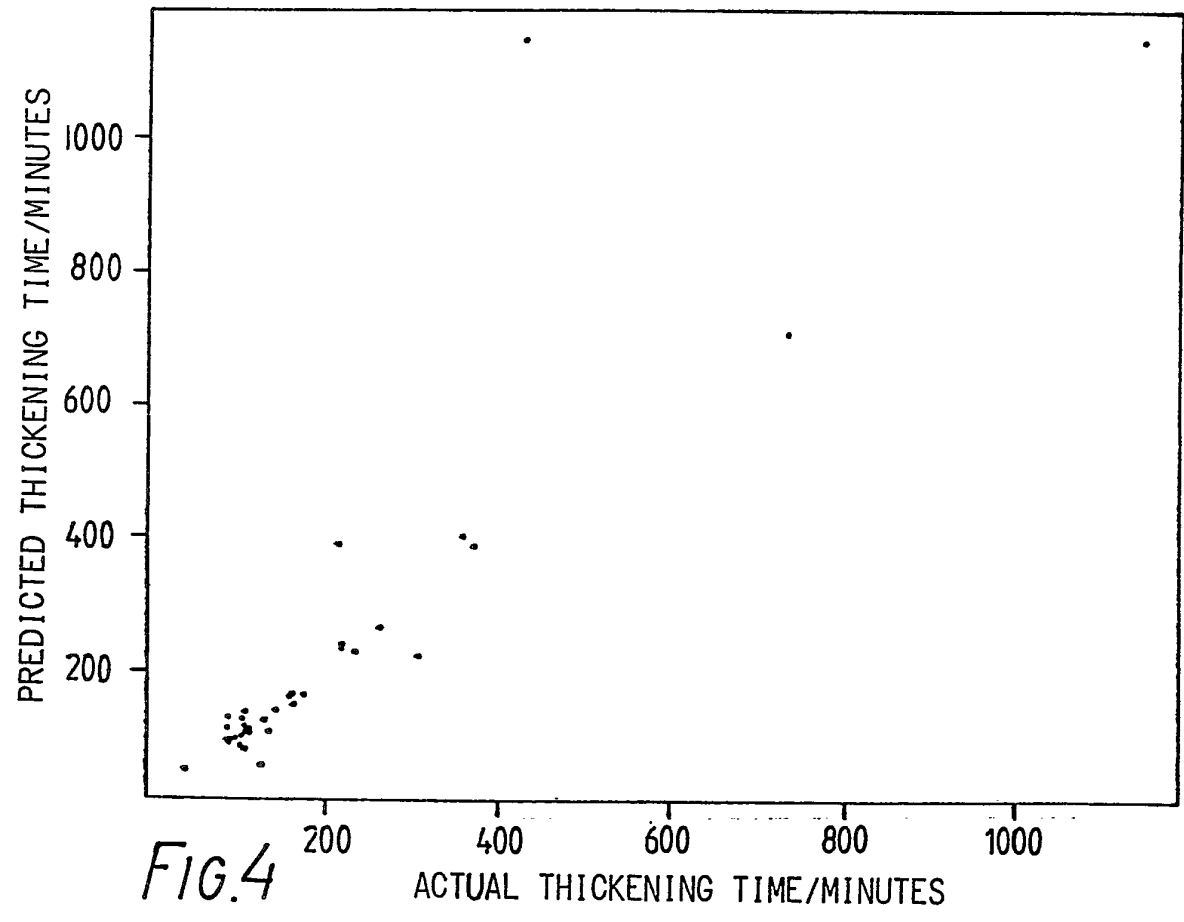
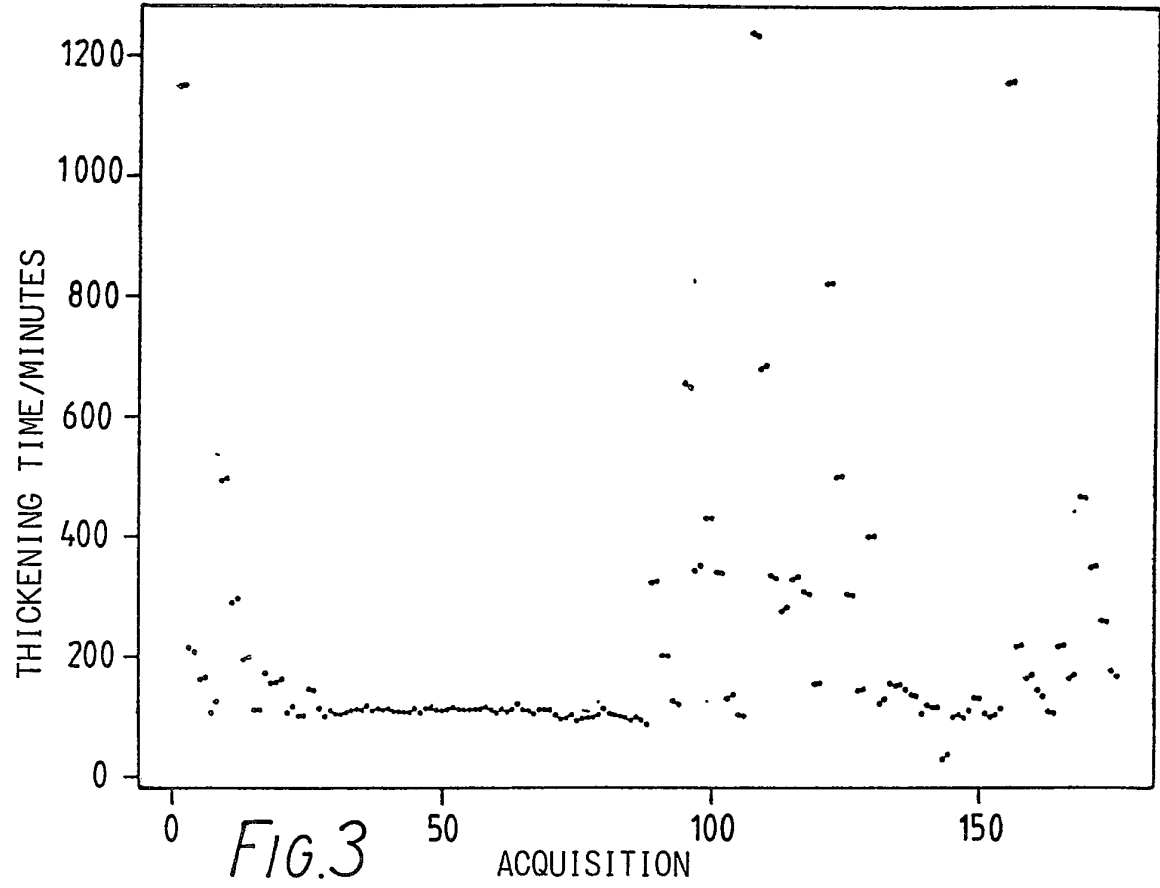


FIG.2

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METHOD FOR PREDICTING CEMENT PROPERTIES

The present invention relates to a method for predicting properties of cement. In particular, the method provides a method of predicting the thickening time of a cement slurry although it is by no means restricted to this use.

In oilwell drilling, cement is used to secure a lining or casing inside a drilled hole. The casing is usually a steel tube and cement slurry is pumped between the casing and the borehole wall and allowed to set, so securing the casing in place. Casing is cemented into a borehole for various reasons. The casing prevents any enlargening of the hole by contact with the drill string or erosion by drilling mud and cuttings. This is particularly important where the borehole encounters soft underground formations. The cement also provides a seal between underground formations so that, for example, water at one level is not contaminated by oil flowing from another level via the borehole. Cement also seals the drilled wall of the borehole which can prevent gas entering the well while it is being drilled which can cause blow-out.

In a typical cementing operation, casing is run into the borehole and cement is pumped from the surface through the casing such that it fills the annulus between the outer surface of the casing and the borehole wall from the bottom up. During this operation it is necessary for the cement to flow relatively easily so that it can be pumped and can fill the entire annulus. Once the cement is in place, it is desirable that it should set in a relatively short time in order that drilling can recommence. The time after mixing a cement slurry at which pumping is no longer possible because the cement has started to set is known as the thickening time and the composition of the slurry is selected according to the required thickening time. A knowledge-based slurry design system has been proposed by Dowell Schlumberger of Saint Etienne, France (see paper from Fourth Annual Conference on Artificial Intelligence in Petroleum Exploration and Production, Texas A&M University 1991) which relies on a large cement slurry database which can be consulted for proposals of slurries according to the conditions chosen. Before a slurry is pumped into a well, it is necessary to test the thickening time of a sample of the slurry. Thickening time measurements are made in a pressurised consistometer which conforms to the specification defined in API Spec. 10. The measurement is performed by first mixing a cement slurry, in accordance with a defined procedure and specified solid to water ratio, prior to placing a required quantity of the slurry in a suitably calibrated consistometer. The subsequent consistometry measurement involves raising the temperature and pressure of the cement to specified values at specified rates while a consistency measurement is being made. After reaching the specified conditions, the temperature and pressure are stabilised and the consistency

of the cement is measured continuously. The time at which the cement reaches a specified consistency is the thickening time. Thickening times can be measured in accordance with one of 20 different schedules. Each schedule has a specified heating rate leading to a specified final temperature and pressure.

Since the standard API measurement attempts to simulate, to some degree, the conditions encountered in a well, the time taken to test each slurry is considered to be close to the actual thickening time of the cement which can often be in the order of 3-6 hours. This, together with the nature of the equipment used, makes thickening time measurement expensive in terms of both cost and time.

It has been previously proposed to predict the thickening time of a cement by measuring one or more properties of the neat cement powder. This technique is based on regression analysis of the measured properties and observed thickening time (see *Cement and Concrete Research*. Vol 16. pp190-198, 1986 Pergamon Press Ltd, *Prediction of thickening time of well cements from Blaine air permeability*, L P Hunt). In this article, it is proposed to predict thickening time of class G and H cements from measurement of Blaine fineness of the neat cement powder using a linear regression analysis technique. While other properties are measured and do improve the prediction, it is proposed that only the fineness measurement is worth measuring. It is not known whether this method has even been used successfully and is considered of doubtful value since only properties of neat cement are measured and other factors known to affect thickening time of a slurry are ignored, eg the presence of a retarder or accelerator.

It is an object of the present invention to provide a method which can usefully predict the thickening time of a cement slurry.

In its broadest aspect, the present invention provides a method of predicting a desired property, such as thickening time, of a cement slurry comprising measuring or determining other properties of a slurry composition and obtaining a predicted value of the desired property by applying values representative of the other properties to a model formed by determining the other properties for a series of cement compositions and correlating these with measured values of the desired property.

In one embodiment the method comprises measuring and determining the other properties and inputting values corresponding to said properties to a neural network device configured to output a value representative of the desired property, the neural network device being a) configured to utilise each of said values as input values, b) provided with at least one hidden layer of at least one node, and c) trained with a dataset comprising series of values of said properties and a value corresponding to the desired property when measured for a slurry having the measured properties.

In another embodiment, the invention comprises obtaining the infrared spectrum of the cement or cement slurry and correlating this information with thickening time to provide the appropriate model which is consulted when an unknown cement is tested. The infrared spectra can be analysed by the neural network arrangement specified above or any suitable multivariate statistical method.

The present invention will now be described by way of example, with reference to the accompanying drawings, in which:

- Figure 1 shows a schematic view of a single neuron in an artificial neural network;
- Figure 2 shows a schematic view of a simple artificial neural network;
- Figure 3 shows the thickening times for a number of cement compositions in a training set; and
- Figure 4 shows the predicted thickening time plotted against measured thickening times for a variety of compositions.

The thickening time of a cement is dependent on a number of properties including the mineral composition of neat cement, the amounts and relative proportions of additives and the thickening time schedule. The complex interrelationships are difficult to define and have so far defied comprehensive mathematical description. One embodiment of the present invention proposes using computer-based artificial neural networks as the framework for predicting thickening times from measurable properties of cement.

The basic unit of an artificial neural network is the neuron or node. In computational terms this comprises a processing element which combines a set of numerical inputs to produce a single numerical output. The neuron generates an output signal in response to the input signals it receives, the strength of which is usually the sum of all the input signals transformed by a mathematical expression called a "transfer function".

Figure 1 shows a schematic of a simple neuron system. Each neuron in layer 1 is ascribed a number y_i which is to be thought of as its output value. The i th neuron makes a contribution to the input for neuron j which is equal to the value of y_i multiplied by a weighting factor W_{ij} . The summation of the individual contributions from all neurons in the i th layer is called the activation of neuron j . Algebraically, the activation X_j is calculated from:

$$X_j = \sum_i y_{ij} - \theta_j, \quad (1)$$

where θ_j is an empirical coefficient called the bias of neuron j . The weighted sum is the most common activation function but others are sometimes used. Occasionally input

signals are multiplied rather than summed. Once X_j is known, the output value of neuron j , y_i , is calculated from the transfer function:

$$y_i = f(X_j). \quad (2)$$

The most common transfer function is a sigmoid:

$$f(X_j) = \frac{1}{1 + e^{-X_j}}. \quad (3)$$

However, other transfer functions may also be used such as linear or hyperbolic tangent.

Any number of neurons may be arranged to construct an artificial neural network. Networks are composed of layers of neurons where the outputs from neurons in one layer constitute the inputs to neurons in the next layers. Layers between the input and output layers are called hidden layers. The structure forms a complex interrelated network which accepts numerical signals from input variables and transmits these signals through the network such that the outputs are a modified representation of the combined inputs as in Figure 2. The general objective is to select a network architecture and a set of weights obtaining by training such that, for given input data, the outputs from the final layer match the values of selected dependent variables or target values with an acceptable tolerance.

Different network architectures are distinguished by the number of layers of nodes, the number of nodes in each layer and the extent to which the nodes are connected. Common network architectures have each node connected to every node in the preceding layer but unconnected to nodes in the same layer. The most useful and general neural network is called the multilayer perceptron (MLP). This type of network has one or more hidden layers for which the connectivity between the nodes can be varied according to the problem in question. In fact, it can be shown that any non-linear mapping needs no more than two hidden layers but generally it is preferable to restrict this number to one since additional layers greatly increase training times. The topology, the connection weights and the activation levels are together called the internal representation of the neural network.

Once a network architecture has been selected, the computational issues are concerned with determining values of the connection weights which minimise the difference between the network outputs and the target values. The technique for optimising the weights in a MLP is an iterative technique called back propagation (Rumelhart D E and McClelland J L, eds. "Parallel Distribution Processing: Explorations in the Microstructure of Cognition", 1986, Volume 1, *Foundations*, MIT

Press). The technique, which is a variation on the method of steepest descent (Press W H, Flannery B P, Teukolsky S A , and W T Vetterling, "Numerical Recipes: The Art of Scientific Computing", 1986, Chapter 10, Cambridge University Press), minimizes the difference between the predicted output and the true output. The procedure for optimising the fitting parameters is called training. The prediction of the target variables for an independent dataset, on which the network has not been trained, is called generalisation.

There are two major factors which need to be considered in order to ensure that a neural network can generalise. These are (a) the nature and quality of data and (b) the architecture of the neural network. As a rule, the number of required examples for training is about ten times the number of input plus output variables, although the number may vary from problem to problem. At the present time, there are no known rules which can be invoked to determine the optimum network topology for any given problem: the selection of an appropriate architecture is to a large extent a matter of trial and error.

In the present case the data in the input layer and the target values represent determinable or measurable properties of the cement. The input values need not have well established physical relationships with the target variables. For example, in some applications an index number representing a class of cement may be used as an alternative to detailed measurements on the properties of the cement.

In one embodiment of the present invention, an artificial neural network is configured to predict cement thickening times using a primary dataset for training and a commercially available neural network software package such as Neural Works Professional II/Plus.

The primary training dataset includes data on 130 oilfield cements covering classes A, B, C, G and H. The measured data for each cement is shown in Table 2 and includes the following:

- (a) The percentage by weight of the minerals tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A) and calcium aluminoferrite (Fer) as predicted by the Bogue calculation (Bogue R H, "Calculation of the compounds in portland cement", Ind. Eng. Chem. Anal., 1, 192-197, 1929); this data represents four independent input variables in the dataset;
- (b) Total percentage by weight of sulphate (SO_3);
- (c) Blaine surface area in units of $m^2 kg^{-1}$ (Blaine);
- (d) Percentage by weight of magnesium oxide (MgO), total alkali content (Alk) and free lime (F.Lime) (three independent input variables);
- (e) Percentage loss on ignition (LOI);
- (f) Insoluble residue (IR)

- (g) Water-to-solid ratio for all cement slurries (W/S);
- (h) Weight percent of sodium chloride (NaCl) retarder in some cement blends;
- (i) Weight percent of calcium chloride (CaCl) accelerator in some cement blends;
- (j) Thickening time schedules defined by well depth (Depth), bottom hole temperature (BHT) and bottom hole pressure (BHP) (3 input variables);
- (k) Thickening time to 100 Bearden units (T/100).

In total the input data is characterised by 16 input variables. The data includes no cements known to cause problems in oilfield cementing applications.

Figure 3 shows the thickening time for 90 cements selected randomly from the primary dataset. The abscissa is the order in which the data was selected. Many of the cements show a thickening time of around 100 minutes although there is a spread of data. The band of measurements in the middle of the plot is for a set of cements which showed little variance in composition, surface area or thickening time. The data at very high thickening times are for a range of cements retarded with sodium chloride. The variation in the mineral compositions and the sulphate contents, for the entire dataset, were within the bounds normally encountered for oil-well cements.

Initially, a range of networks were trained on this data each having one hidden layer and a single target output which was the thickening time. The number of nodes in the hidden layer was varied between 1 and 12. Figure 4a shows the predicted and measured thickening times for the calibration data calculated using a network with six nodes in the hidden layer. The mean residual error on the validation is $\pm 16\%$. Figure 4b shows the distribution of percentage errors. Over 80% of the data is predicted with an error of less than 20% and around 50% of the data predicted with an accuracy of better than 5%.

The precision of the network predictions is almost independent of the number of nodes in the hidden layer of the network. This observation is shown in Table 1 which depicts the errors on validation and calibration plus the number of predictions falling below a specified error limit.

In order to deduce the minimum number of input variables necessary to predict thickening times adequately the data set was progressively and systematically reduced and the six node network re-trained after each reduction.

The minimum number of input variables required to predict thickening times of a cement slurry composition with a mean error of less than 17% is 9. These are the 4 basic cement minerals, solid to water/ratio, Blaine surface area, sodium chloride concentration, calcium chloride concentration, and any one from bottom hole pressure, well depth or bottom hole temperature.

Minor improvements could be obtained by including more than the 9 named variables. Reducing the data to less than the number of named variables increased the mean error of prediction to 30% or higher.

For neat cements, containing no retarder or accelerator, mean errors in prediction of less than 16% were achieved with seven input variables using the six node network. The 7 input variables are those above excluding sodium chloride or calcium chloride.

The methods herein describe the prediction of a single performance property of oil-well cements from measurable variables including cement composition. It has been proposed that cement composition can be predicted reliably from spectroscopic infrared measurements on the dry cement powder. It is therefore proposed that the composition of the cements may be replaced by specified spectroscopic features of the cement. These features may be digitised interferograms, absorbance measurements at specified frequencies or other parameters designed to compactly represent spectral measurements. The thickening time of cements may be influenced by non-chemical properties of cement particles including particle size distribution, crystallographic defects in cement grains and compositional variations between cement grains. These features and others have subtle effects on the infrared spectra of powders and the spectra therefore contain useful information which may be correlated to thickening times with optimised neural networks along the lines proposed above.

Table 1 - Error versus Number of Nodes

NODES	% ER TRN	% ER VALID	N < 20%	N < 10%	N < 5%
1	14.0	23	30	21	10
2	8.9	19.6	31	27	16
3	9.8	16.7	33	24	15
4	6.0	16.6	33	24	18
5	10.7	16.5	33	23	17
6	3.2	15.4	32	27	20
7	9.42	14.1	33	24	16
8	9.43	14.9	34	24	17
10	2.4	16.7	33	30	20
12	4.5	23.3	32	26	19

Table 2 - Training Dataset

No	C3S	C2S	C3A	Fer	SO3	MgO	LOI	IR	Alk	F.Lime	Blaine	NaCl	CaCl2	W/S	Depth	BHT	BHP	T/100
1G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	3100	0.0	0.0	44	2000	33	1540	216
2G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	3100	0.0	0.0	44	4000	39	2580	164
3G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	3100	0.0	0.0	44	6000	45	3870	145
4G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	3100	0.0	0.0	44	8000	52	5160	109
5G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	3100	6.0	0.0	60	2000	33	1540	497
6G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	3100	6.0	0.0	60	4000	39	2580	373
7G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	3100	6.0	0.0	60	6000	45	3870	292
8G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	3100	6.0	0.0	60	8000	52	5160	198
9G	60.5	16	2.0	16.0	2.8	0.7	1.2	0.2	0.40	0.3	3700	0.0	0.0	44	8000	52	5160	111
1H	62.7	15	1.3	16.0	2.7	0.7	1.2	0.1	0.29	0.25	2960	0.0	0.0	38	8000	52	5160	115
11H	62.7	15	1.3	16.0	2.7	0.7	1.2	0.1	0.29	0.25	2960	0.0	0.0	46	8000	52	5160	175
12H	58.9	16	1.5	16.0	2.8	0.7	1.2	0.23	0.29	0.40	2837	0.0	0.0	38	8000	52	5160	110
13H	58.9	16	1.5	16.0	2.8	0.7	1.2	0.23	0.29	0.40	2837	0.0	0.0	46	8000	52	5160	160
14H	58.9	16	1.5	16.0	2.8	0.7	1.2	0.23	0.29	0.40	2837	0.0	0.0	38	8000	52	5160	110
15H	58.9	16	1.5	16.0	2.8	0.7	1.2	0.23	0.29	0.40	2837	0.0	0.0	46	8000	52	5160	160
16H	56.0	17	1.8	16.0	2.7	0.7	1.2	0.26	0.29	0.35	2990	0.0	0.0	38	8000	52	5160	105
17H	56.0	17	1.8	16.0	2.7	0.7	1.2	0.26	0.29	0.35	2990	0.0	0.0	46	8000	52	5160	149
18G	54.0	22.0	1.7	15.0	2.3	0.8	0.8	0.15	0.40	0.35	3200	0.0	0.0	44	8000	52	5160	107
19G	54.0	23.0	1.7	15.0	2.3	0.8	0.9	0.2	0.40	0.35	3200	0.0	0.0	44	8000	52	5160	117
20G	54.0	23.0	1.7	15.0	2.4	0.8	1.0	0.2	0.37	0.35	3200	0.0	0.0	44	8000	52	5160	113
21G	54.0	21.0	1.7	15.0	2.4	0.8	1.1	0.2	0.37	0.35	3200	0.0	0.0	44	8000	52	5160	110
22G	55.7	20.7	1.71	15.6	2.37	0.84	0.97	0.15	0.38	0.35	3200	0.0	0.0	44	8000	52	5160	108
23G	57.9	17.6	1.66	15.6	2.35	0.82	0.97	0.17	0.35	0.35	3200	0.0	0.0	44	8000	52	5160	114
24G	59.3	16.9	1.60	15.1	2.26	0.81	1.06	0.17	0.33	0.35	3200	0.0	0.0	44	8000	52	5160	112
25G	58.2	17.7	1.54	15.3	2.35	0.81	1.36	0.18	0.32	0.35	3200	0.0	0.0	44	8000	52	5160	114
26G	57.9	18.0	1.34	15.21	2.30	0.79	1.04	0.16	0.35	0.35	3200	0.0	0.0	44	8000	52	5160	113
26G	55.76	21.6	1.60	15.63	2.38	0.82	1.01	0.15	0.34	0.35	3200	0.0	0.0	44	8000	52	5160	116
28G	56.40	19.7	1.61	15.5	2.29	0.84	1.09	0.14	0.34	0.35	3200	0.0	0.0	44	8000	52	5160	114
29G	55.80	21.1	1.57	15.70	2.23	0.82	0.89	0.13	0.36	0.35	3200	0.0	0.0	44	8000	52	5160	112
30G	57.60	19.3	1.63	15.53	2.19	0.82	1.94	0.15	0.36	0.35	3200	0.0	0.0	44	8000	52	5160	108
31G	52.00	23.9	1.78	15.24	2.28	0.80	1.18	0.14	0.37	0.35	3200	0.0	0.0	44	8000	52	5160	111
32G	54.00	22.39	1.69	15.31	2.26	0.77	1.01	0.16	0.35	0.35	3200	0.0	0.0	44	8000	52	5160	116
33G	54.00	22.80	1.66	15.60	2.25	0.75	1.27	0.16	0.35	0.35	3200	0.0	0.0	44	8000	52	5160	116
34G	57.30	19.30	1.32	15.00	2.41	0.75	1.12	0.17	0.34	0.35	3200	0.0	0.0	44	8000	52	5160	114
35G	56.3	19.9	1.48	15.50	2.33	0.84	0.96	0.16	0.36	0.35	3200	0.0	0.0	44	8000	52	5160	114
36G	54.5	21.4	1.50	15.51	2.31	0.75	1.27	0.16	0.34	0.35	3200	0.0	0.0	44	8000	52	5160	114
37G	57.6	18.2	1.28	15.40	2.47	0.74	0.98	0.15	0.36	0.35	3200	0.0	0.0	44	8000	52	5160	115

No	C ₃ S	C ₂ S	C ₃ A	Fer	SO ₃	MgO	LOI	IR	Alk	F.Lime	Blaine	NaCl	CaCl ₂	W/S	Depth	BHT	BHP	T/100
38G	58.2	17.9	1.47	15.30	2.24	0.82	0.89	0.16	0.36	0.35	3200	0.0	0.0	44	8000	52	5160	115
39G	57.2	19.2	1.45	15.70	2.34	0.82	1.08	0.14	0.36	0.35	3200	0.0	0.0	44	8000	52	5160	113
40G	58.1	19.3	1.63	14.80	2.44	0.83	0.99	0.16	0.34	0.35	3200	0.0	0.0	44	8000	52	5160	114
41G	59.5	17.9	1.58	14.80	2.31	0.81	1.03	0.16	0.31	0.35	3200	0.0	0.0	44	8000	52	5160	115
42G	57.5	19.1	1.94	14.60	2.18	0.77	1.04	0.18	0.32	0.35	3200	0.0	0.0	44	8000	52	5160	115
43G	58.1	18.3	1.71	14.60	2.23	0.80	0.93	0.18	0.36	0.35	3200	0.0	0.0	44	8000	52	5160	113
44G	54.7	22.1	1.72	14.80	2.29	0.76	1.07	0.19	0.32	0.35	3200	0.0	0.0	44	8000	52	5160	114
45G	57.3	19.6	1.64	14.70	2.27	0.73	1.06	0.18	0.34	0.35	3200	0.0	0.0	44	8000	52	5160	116
46G	56.7	20.4	1.77	18.20	2.26	0.77	1.00	0.17	0.31	0.35	3200	0.0	0.0	44	8000	52	5160	114
47G	57.5	19.7	1.73	14.90	2.07	0.77	1.20	0.19	0.31	0.35	3200	0.0	0.0	44	8000	52	5160	113
48G	58.0	19.2	1.78	14.90	2.28	0.74	1.13	0.16	0.34	0.35	3200	0.0	0.0	44	8000	52	5160	115
49G	57.6	28.9	1.49	14.90	2.20	0.72	1.07	0.18	0.34	0.35	3200	0.0	0.0	44	8000	52	5160	107
50G	57.1	19.8	1.38	15.05	2.21	0.75	1.00	0.17	0.34	0.35	3200	0.0	0.0	44	8000	52	5160	113
51G	54.0	20	2.50	14.5	1.70	0.60	1.2	0.20	0.45	0.4	3110	0.0	0.0	44	8000	52	5160	91
52G	55.0	20	2.5	14.5	1.70	0.60	0.8	0.20	0.54	0.4	3110	0.0	0.0	44	8000	52	5160	104
53G	55.0	20	2.0	14.50	1.80	0.60	0.9	0.20	0.44	0.4	3090	0.0	0.0	44	8000	52	5160	100
54G	53.0	20	2.0	14.5	1.80	0.70	0.9	0.20	0.53	0.4	3090	0.0	0.0	44	8000	52	5160	95
55G	52.0	20	2.3	14.6	1.80	0.60	0.9	0.20	0.55	0.4	3120	0.0	0.0	44	8000	52	5160	95
56G	55.0	20	2.2	14.6	1.70	0.60	1.1	0.20	0.41	0.4	3140	0.0	0.0	44	8000	52	5160	100
57G	52.0	20	2.4	14.7	1.90	0.60	1.0	0.20	0.54	0.4	3170	0.0	0.0	44	8000	52	5160	93
58G	54.0	20	1.9	15.2	1.70	0.70	1.1	0.20	0.35	0.4	3010	0.0	0.0	44	8000	52	5160	105
59G	58.0	20	2.3	13.4	1.80	0.60	1.1	0.20	0.33	0.4	3110	0.0	0.0	44	8000	52	5160	106
60G	54.0	20	2.4	13.8	1.90	0.60	1.0	0.20	0.51	0.4	3260	0.0	0.0	44	8000	52	5160	105
61G	53.0	20	2.5	14.0	1.80	0.60	1.1	0.20	0.50	0.4	3070	0.0	0.0	44	8000	52	5160	102
62G	54.0	20	2.5	14.0	1.90	0.60	1.1	0.20	0.54	0.4	3010	0.0	0.0	44	8000	52	5160	96
63G	52.0	20	2.3	14.9	1.90	0.70	1.2	0.20	0.55	0.4	3020	0.0	0.0	44	8000	52	5160	100
64G	53.0	20	2.3	15.4	1.90	0.70	1.2	0.20	0.57	0.4	3250	0.0	0.0	44	8000	52	5160	96
66A	60	10	11	7	2.5	2.0	0.9	0.20	0.4	0.4	3250	0.0	0.0	46	1000	27	1020	324
67A	60	10	11	7	2.5	2.0	0.9	0.20	0.4	0.4	3250	0.0	0.0	46	2000	33	1540	264
68A	60	10	11	7	2.5	2.0	0.9	0.20	0.4	0.4	3250	0.0	0.0	46	4000	39	2580	202
69A	60	10	11	7	2.5	2.0	0.9	0.20	0.4	0.4	3250	0.0	0.0	46	6000	45	3870	128
70A	60	10	11	7	2.5	2.0	0.9	0.20	0.4	0.4	3250	6.0	0.0	63	1000	27	1020	1149
71A	60	10	11	7	2.5	2.0	0.9	0.20	0.4	0.4	3250	6.0	0.0	63	2000	33	1540	654
72A	60	10	11	7	2.5	2.0	0.9	0.20	0.4	0.4	3250	6.0	0.0	63	4000	39	2580	345
73A	60	10	11	7	2.5	2.0	0.9	0.20	0.4	0.4	3250	6.0	0.0	63	6000	45	3870	309
74B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.0	0.0	46	1000	27	1020	431
75B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.0	0.0	46	2000	33	1540	342
75B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.0	0.0	46	4000	39	2580	235
76B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.0	0.0	46	6000	45	3870	132

No	C ₃ S	C ₂ S	C ₃ A	Fer	SO ₃	MgO	LOI	IR	Alk	F.Lime	Blaine	NaCl	CaCl ₂	W/S	Depth	BHT	BHP	T/100
77B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.0	0.0	46	8000	52	5160	105
78B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.0	0.0	46	10000	62	7480	91
79B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	6.0	0.0	63	1000	27	1020	1236
80B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	6.0	0.0	63	2000	33	1540	678
81B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	6.0	0.0	63	4000	39	2580	360
82B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	6.0	0.0	63	6000	45	3870	336
83B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	6.0	0.0	63	8000	52	5160	276
84B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	6.0	0.0	63	10000	62	7480	219
85C	58	16	10	10	3.0	2.0	1.2	0.20	0.4	0.4	4400	0.0	0.0	56	1000	27	1020	330
86C	58	16	10	10	3.0	2.0	1.2	0.20	0.4	0.4	4400	0.0	0.0	56	2000	33	1540	309
87C	58	16	10	10	3.0	2.0	1.2	0.20	0.4	0.4	4400	0.0	0.0	56	4000	39	2580	220
88C	58	16	10	10	3.0	2.0	1.2	0.20	0.4	0.4	4400	0.0	0.0	56	6000	45	3870	155
89C	58	16	10	10	3.0	2.0	1.2	0.20	0.4	0.4	4400	6.0	0.0	77	1000	27	1020	820
90C	58	16	10	10	3.0	2.0	1.2	0.20	0.4	0.4	4400	6.0	0.0	77	2000	33	1540	735
91C	58	16	10	10	3.0	2.0	1.2	0.20	0.4	0.4	4400	6.0	0.0	77	4000	39	2580	500
92C	58	16	10	10	3.0	2.0	1.2	0.20	0.4	0.4	4400	6.0	0.0	77	6000	45	3870	305
93A	62	10	11	7	2.2	1.3	2.0	0.5	0.4	0.4	3250	0.0	0.0	46	1000	27	1020	430
94A	62	10	11	7	2.2	1.3	2.0	0.5	0.4	0.4	3250	0.0	0.0	46	6000	45	3870	145
95B	61	17	1	16	2.0	0.7	1.2	0.3	0.4	0.4	3200	0.0	0.0	46	1000	27	1020	400
96B	61	17	1	16	2.2	0.7	1.2	0.3	0.4	0.4	3200	0.0	0.0	46	6000	45	3870	165
97H	57	19	1.2	14.0	2.4	0.7	1.0	0.3	0.4	0.4	2330	0.0	0.0	38	8000	52	5160	123
98H	54	23	1.3	14.3	2.1	0.7	1.0	0.3	0.4	0.4	1900	0.0	0.0	38	8000	52	5160	156
99H	57	21	2.3	14.3	1.8	0.7	1.0	0.3	0.4	0.4	2420	0.0	0.0	38	8000	52	5160	138
100H	56	22	1.5	14.0	2.3	0.7	1.0	0.3	0.4	0.4	2020	0.0	0.0	38	8000	52	5160	154
101H	48	28	3.5	11.5	2.0	0.7	1.0	0.3	0.4	0.4	2220	0.0	0.0	38	8000	52	5160	138
102H	50	27	2.7	11.8	2.1	0.7	1.0	0.3	0.4	0.4	2270	0.0	0.0	38	8000	52	5160	133
103H	46	29	0.8	16.6	2.8	0.7	1.0	0.3	0.4	0.4	2740	0.0	0.0	38	8000	52	5160	106
104H	49	25	0.3	17.0	2.8	0.7	1.0	0.3	0.4	0.4	2810	0.0	0.0	38	8000	52	5160	117
105H	62	14	3.1	10.6	2.4	0.7	1.0	0.3	0.4	0.4	3360	0.0	0.0	38	8000	52	5160	46
106A	57	17	7.7	8.5	2.8	0.7	1.0	0.3	0.4	0.4	3680	0.0	0.0	38	8000	52	5160	30
107A	56	18	4.6	9.8	2.6	0.7	1.0	0.3	0.4	0.4	2650	0.0	0.0	33	8000	52	5160	101
108G	67	10	1.0	16	1.8	1.15	0.88	0.04	0.62	0.4	2860	0.0	0.0	45	8000	52	5160	111
109G	60	16	1	13	2.2	0.7	1.0	0.3	0.4	0.4	3190	0.0	0.0	45	8000	52	5160	99
110G	64	12	0.4	12.9	2.5	0.7	1.6	0.01	0.06	2.9	3910	0.0	0.0	45	8000	52	5160	132
111G	53	13.7	10.4	9.1	2.5	0.7	1.1	1.9	0.29	0.5	3910	0.0	0.0	46	6000	45	3870	130
112G	56.5	21.1	5.2	10.3	2.2	1.33	1.0	1.0	0.5	0.0	2753	0.0	0.0	44	8000	52	5160	106
113G	57.0	20	2.4	15.0	1.9	0.55	1.0	0.2	0.5	0.0	2753	0.0	0.0	44	8000	52	5160	104
114G	55.6	20	3.24	14.3	2.54	1.36	1.5	0.2	0.57	0.0	2800	0.0	0.0	44	8000	52	5160	92
115G	60	17	1	16	2.0	0.6	1.2	0.3	0.4	0.4	3300	0.0	0.0	46	8000	52	5160	115

No	C ₃ S	C ₂ S	C ₃ A	Fer	SO ₃	MgO	LOI	IR	Alk	F.Lime	Blaine	NaCl	CaCl ₂	W/S	Depth	BHT	BHP	T/100
116G	60	17	1	16	2.0	0.6	1.2	0.3	0.4	0.4	3300	0.45	0.011	46	8000	52	5160	65
117G	60	17	1	16	2.0	0.6	1.2	0.3	0.4	0.4	3300	0.00	0.39	46	8000	52	5160	50
118A	62	10	11	7	2.2	1.3	2.0	0.5	0.4	0.4	3250	0.45	0.01	46	1000	27	1020	375
119A	62	10	11	7	2.2	1.3	2.0	0.5	0.4	0.4	3250	0.45	0.01	46	6000	45	3870	100
120A	62	10	11	7	2.2	1.3	2.0	0.5	0.4	0.4	3250	0.0	0.39	46	1000	27	1020	215
121A	62	10	11	7	2.2	1.3	2.0	0.5	0.4	0.4	3250	0.0	0.39	46	6000	45	3870	85
122B	61	17	1	16	2.0	0.7	1.2	0.3	0.4	0.4	3200	0.45	0.01	46	1000	27	1020	365
123B	61	17	1	16	2.2	0.7	1.2	0.3	0.4	0.4	3200	0.45	0.01	46	6000	45	3870	95
124B	61	17	1	16	2.0	0.7	1.2	0.3	0.4	0.4	3200	0.0	0.39	46	1000	27	1020	190
125B	61	17	1	16	2.2	0.7	1.2	0.3	0.4	0.4	3200	0.0	0.39	46	6000	45	3870	65
126A	60	10	11	7	2.5	2.0	0.9	0.20	0.4	0.4	3250	0.45	0.01	47	1000	27	1020	268
127A	60	10	11	7	2.5	2.0	0.9	0.20	0.4	0.4	3250	0.45	0.01	47	2000	33	1540	220
128A	60	10	11	7	2.5	2.0	0.9	0.20	0.4	0.4	3250	0.45	0.01	47	4000	39	2580	134
129A	60	10	11	7	2.5	2.0	0.9	0.20	0.4	0.4	3250	0.45	0.01	47	6000	45	3870	117
130B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.45	0.01	47	1000	27	1020	315
131B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.45	0.01	47	2000	33	1540	222
132B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.45	0.01	47	4000	39	2580	130
133B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.45	0.01	47	6000	45	3870	116
134B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.45	0.01	47	8000	52	5160	87
135B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.45	0.01	47	10000	62	7480	74
136C	58	16	10	10	3.0	2.0	1.2	0.20	0.4	0.4	4400	0.45	0.01	57	1000	27	1020	282
137C	58	16	10	10	3.0	2.0	1.2	0.20	0.4	0.4	4400	0.45	0.01	57	2000	33	1540	230
138C	58	16	10	10	3.0	2.0	1.2	0.20	0.4	0.4	4400	0.45	0.01	57	4000	39	2580	159
139C	58	16	10	10	3.0	2.0	1.2	0.20	0.4	0.4	4400	0.45	0.01	57	6000	45	3870	121
140G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	3100	0.45	0.01	45	2000	33	1540	216
141G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	3100	0.45	0.01	45	4000	39	2580	164
142G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	3100	0.45	0.01	45	6000	45	3870	145
143G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	3100	0.45	0.01	45	8000	52	5160	109
144B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.45	0.2	47	1000	27	1020	275
145B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.45	0.2	47	2000	33	1540	178
146B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.45	0.2	47	4000	39	2580	157
147B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.45	0.4	47	1000	27	1020	215
148B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.45	0.4	47	2000	33	1540	141
149B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.45	0.4	47	4000	39	2580	111
150B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.45	0.8	47	1000	27	1020	187
151B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.45	0.8	47	2000	33	1540	128
152B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	0.45	0.8	47	4000	39	2580	109
153G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	3100	0.45	0.39	46	2000	35	1540	145
154G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	3100	0.00	0.39	44	4000	33	2580	95

No	C ₃ S	C ₂ S	C ₃ A	Fer	SO ₃	MgO	LOI	IR	Alk	F.Lime	Blaine	NaCl	CaCl ₂	W/S	Depth	BHT	BHP	T/100
155B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	3.4	0.0	46	6000	45	3870	169
156B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	3.4	0.0	46	8000	52	5160	136
157B	61	17	15	2	2.5	2.0	0.9	0.20	0.4	0.4	3200	3.4	0.0	47	10000	62	7480	112
158G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	2600	0.00	0.00	38	2000	33	1540	216
159G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	2600	0.00	0.00	38	4000	39	2580	164
160G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	2600	0.00	0.00	38	6000	45	3870	145
161G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	2600	0.00	0.00	38	8000	52	5160	109
162G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	2600	0.45	0.01	39	2000	33	1540	162
163G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	2600	0.45	0.01	39	4000	39	2580	106
164G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	2600	0.45	0.01	39	6000	45	3870	89
165G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	2600	0.45	0.01	39	8000	52	5160	69
166G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	2600	6.00	0.00	52	2000	33	1540	466
167G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	2600	6.00	0.00	52	4000	39	2580	350
168G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	2600	6.00	0.00	52	6000	45	3870	260
169G	64	14	2.0	15.0	2.0	2.0	0.9	0.2	0.4	0.5	2600	6.00	0.00	52	8000	52	5160	176

Claims:

- 1 A method of predicting the thickening time of a cement slurry comprising measuring or determining a plurality of other properties of the slurry and obtaining a prediction of the thickening time by applying values representing said other properties to a model formed by determining said other properties for a series of cement compositions and correlating these with measured values of the thickening time for the composition in the series.
- 2 A method as claimed in claim 1, comprising inputting values representative of said other properties to an artificial neural network device configured to output a value representative of the predicted thickening time, the artificial neural network device being:
 - a) configured to utilise each of said values representative of said other properties as input values;
 - b) provided with at least one hidden layer of at least one node; and
 - c) trained with a dataset comprising series of values of said properties and values of measured thickening time.
- 3 A method as claimed in claim 1 or 2, wherein said other properties are selected from:
 - (a) percentage by weight of each of the minerals tricalcium silicate, dicalcium silicate, tricalcium aluminate and calcium alumino-ferrate;
 - (b) total percentage by weight of sulphate;
 - (c) Blaine surface area
 - (d) Percentage by weight of each of MgO, total alkali content and free lime;
 - (e) percentage loss on ignition;
 - (f) Insoluble residue (IR)
 - (g) Water-to-solid ratio for all cement slurries (W/S);
 - (h) Weight percent of sodium chloride (NaCl) retarder in some cement blends;
 - (i) Weight percent of calcium chloride (CaCl) accelerator in some cement blends;
 - (j) Thickening time schedules defined by well depth (Depth), bottom hole temperature (BHT) and bottom hole pressure (BHP) (3 input variables);
 - (k) Thickening time to 100 Bearden units (T/100).
- 4 A method as claimed in claim 3, wherein the number of properties selected is not less than 7.

- 5 A method as claimed in claim 4, wherein the number of properties selected is not less than 9.
- 6 A method as claimed in claim 3 or 4, wherein the input properties are a), c), f) and i) and optionally g) and h).
- 7 A method as claimed in any of claims 2-6, wherein the artificial neural network device is configured to have one or two hidden layers, each with 1-12 nodes.
- 8 A method as claimed in any preceding claim, wherein infrared spectroscopic data is used as one or more of the other properties.
- 9 A method as claimed in claim 1 comprising obtaining infrared spectral data of the cement or slurry under investigation and using this data to obtain the thickening time from the model.

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Patents Act 1977
Examiner's report to the Comptroller under
Section 17 (The Search Report)

Application number

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Relevant Technical fields

(i) UK Cl (Edition K) G1S (SEX, SXX): G1R (RG)

(ii) Int Cl (Edition 5) G01N

Search Examiner

VIC FLETCHER

Databases (see over)

(i) UK Patent Office

(ii) ONLINE DATABASES: WPI

Date of Search

4.3.92

Documents considered relevant following a search in respect of claims

1 TO 9

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
Y	GB 2221042 A (HALUK TORAL &c) whole document	1
Y	US 4648264 A (HALLIBURTON)	1
Y	JP 2052243 A (TODA &c)	1
Y	CN 1038698 A (AUTO ENG. COLLEGE)	1

Category	Identity of document and relevant passages	Relevant to claim(s)

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