

description

The present invention relates to the logging of earth formations, and more particularly to neutron irradiation measurement techniques for in situ determination of earth formation porosities in the vicinity of a borehole passing therethrough.

Present neutron methods for obtaining porosity measurements analyze secondary neutron populations produced by either steady-state or pulsed sources of high energy neutrons. Steady-state sources typically produce neutrons having mean energies of approximately 4-5 Mev. Pulsed (d, t) sources produce neutrons having energies of 14 Mev. In both, the neutrons are moderated by interaction with the nuclei of the materials in the borehole and the surrounding earth formations. When the neutron energies have moderated to below about 0.05 electron volts, they come into thermal equilibrium with their environment. At this point they are referred to as "thermal" neutrons and, on average, lose no further energy. At energies just above thermal up to around 100 electron volts, the neutrons are referred to as "epithermal" neutrons.

Upon reaching the thermal energy range, the neutrons diffuse through the formation and borehole until they are captured by nuclei in the constituent materials. The rate at which a zone of material (formation or borehole) captures the neutrons (or more precisely, the probability of capture) is referred to as the macroscopic capture cross-section of the zone. The macroscopic capture cross-section is, in turn, a result of the combined microscopic capture cross-sections of the various constituent elements and materials constituting the zone. The capture cross-section of chlorine for thermal neutrons is considerably higher than that of most other elements commonly encountered in earth formations of interest. Accordingly, thermal neutron macroscopic capture cross-section measurements can give a good indication of the saline content of the fluids in the zone in question. By combining such information about the saline content of the fluids in the pore spaces of an adjacent earth formation with information about the formation water salinity, porosity measurements, and measurements of formation shaliness, information can be derived which can discriminate oil from salt water filled pore spaces in the vicinity of a well borehole.

Such thermal neutrons are absorbed by other materials as well as chlorine, the macroscopic capture cross-section is also responsive to borehole conditions and to the lithology of the formation materials. Present thermal neutron techniques for obtaining porosity measurements from pulsed neutron tools therefore often involve taking a ratio of the capture gamma ray count rates in two detectors spaced in the tool at different distances from the neutron source. By taking the ratio of the counts, many of these perturbations and some of the effects of borehole parameters can be reduced. However, to take

such ratios the detectors must be gain stabilized, or at least their count rates must drift in exactly the same manner. Pulsed neutron measurement ratios thus obtained are therefore still borehole dependent, dependent on the capture cross-section of the formation, and can be dependent on the specific capture gamma ray energy distribution from the elements present (i.e., can be lithology dependent). In addition, the measurement is often statistically limited because the more distant detector used in the ratio measurement experiences a relatively low count rate in many formations. Nevertheless, a good qualitative porosity indication can often be derived.

Epithermal neutrons behave quite differently from thermal neutrons in the borehole and the formation. Epithermal neutron populations are depleted primarily through moderation by collisions (predominantly elastic) with formation nuclei, rather than by absorption. Epithermal neutron populations are therefore not affected by the various (i.e., borehole and formation) capture cross-sections. Instead, they are moderated and depleted most quickly by collisions with nuclei of similar mass: hydrogen. Since most pore space is filled by hydrogen-rich materials (hydrocarbons or water) while solid formation materials contain much less hydrogen, the rate of decay of an epithermal neutron population gives a good quantitative indication of the amount of hydrogen-containing material present. This, in turn, can be used to measure formation porosities. Further, such epithermal neutron measurements may be made without requiring two separate detectors. U.S. Patents 4,097,737 and 4,266,126, for example, give examples of single detector epithermal neutron methods for measuring formation porosities while minimizing the effects of lithology.

US-A-3487211 describes a method and apparatus for neutron well logging in which the earth formation is irradiated with a pulse of fast neutrons, and the epithermal neutrons in the formation are counted, after each pulse, in two time intervals during their die-away period and, from the ratio of the two counts, a measure of the porosity of the formation is obtained.

However, prior art epithermal neutron porosity methods have typically suffered from several limitations. For example, borehole effects are commonly ignored. That is, since borehole moderation is usually faster than formation moderation, the several measurements which are made are usually delayed until the borehole component has had sufficient time to die away. However, some residual borehole component will usually be present, and neutrons can always be expected to re-enter the borehole from the adjacent earth formation.

Another disadvantage of delaying the measurement gates to allow the borehole component to dissipate is the loss of important information during this long waiting period. Count rates are high and statistically important during

early portion of the epithermal neutron moderation (or die-away) cycle, and such prior art delayed measurement methods fail to utilise this information. Further, as disclosed by the present invention, valuable information can be obtained even earlier from the nature of the epithermal neutron population build-up during and just following the pulse of high energy neutrons.

An important improvement in thermal (as distinguished from epithermal) neutron measurements is disclosed in our European patent specification No. 95900 to which reference should be made for further details. In this invention, at least four, and preferably six, capture gamma ray counts are made starting immediately after thermalization of the fast neutrons. From these measurements both the borehole thermal neutron lifetime component and the earth formation thermal neutron lifetime component are individually calculated using least squares fitting of the count rate data. Rather than ignoring the borehole component, therefore, it is specifically identified, calculated, and separated from the formation component, substantially improving the accuracy of the formation thermal neutron lifetime measurement. Unfortunately, however, the prior art fails to teach how such an improved method might be applied to the measurement of lithology-independent epithermal neutron populations.

With regard to the determination of borehole effects, a paper by J. Czubeck (Czubeck, J. A., "Pulsed Neutron Method for Uranium Well Logging", *Geophysics*, Vol 37, No. 1, February, 1972) indicated from both theory and experimental data that the formation epithermal neutron decay distribution following a neutron burst is, like that of thermal neutron decay, also exponential in form. It may be approximated by:

$$E(t) = A_0 e^{-\alpha t/t_0}$$

where A_0 is a constant related to the initial number of neutrons emitted during the burst and the width and shape of the burst; t_0 is the slowing down (or moderation) time of the source neutrons in the formation, and α is a constant. Hence " α/t_0 " is an epithermal parameter analogous to " Σ " (the formation capture cross-section) for the thermal neutron distributions. Therefore, α/t_0 is a measure of the epithermal neutron "absorption", where "absorption" represents the removal of epithermal neutrons due to thermalization. Experiments have shown that t_0 is not appreciably affected by lithology.

If a borehole epithermal neutron decay term is included in the total epithermal neutron count rate expression, then:

$$E(t) = A_{0B} e^{-\alpha_B t/t_{0B}} + A_{0F} e^{-\alpha_F t/t_{0F}}$$

where the "B" and "F" subscripts relate to the borehole and formation components respectively.

A comparison with well known prior art thermal neutron analyses will show that the epithermal neutron case, as described above, is essentially analogous thereto. What is also noteworthy, however, is that the prior art techniques usually delay measurements until t is sufficiently great that the borehole component has gone essentially to zero. According to the present invention, much earlier data, including data developed by observing the build-up of the epithermal neutron population before the burst of fast neutrons has been concluded, produces an even more sensitive and accurate measurement of formation and/or borehole hydrogen index or porosity.

According to the present invention, there is provided a method of determining the porosity of earth formations in the vicinity of a well borehole passing therethrough, comprising:

(a) emitting, in a portion of the borehole substantially adjacent the formations of interest, repetitive relatively short duration with respect to a typical epithermal neutron decay time constant pulses of fast neutrons for moderation to epithermal energies by interaction with nuclei of materials in the borehole and surrounding earth formations, creating thereby repetitive bursts of populations of epithermal neutrons in the borehole and surrounding earth formations,

(b) detecting epithermal neutrons at a longitudinally spaced distance in the borehole during at least two non-overlapping predetermined time intervals comprising a first interval and a second interval, said detected epithermal neutrons being representative of the epithermal neutron population in at least the surrounding earth formations,

(c) generating at least two count rate signals by generating, during said at least two time intervals, corresponding count rate signals representative of the corresponding said epithermal neutron populations,

(d) obtaining a measurement signal representative of the porosity of the surrounding earth formations by taking a ratio of the count rate signal during said first time interval to the count rate signal during said second time interval; and

(e) recording said measurement signal as a function of borehole depth; characterised in that, in step (b), the first interval substantially spans the build-up of the epithermal neutron population and includes each said fast neutron pulse whereby the count rate signal generated in step (c) in respect thereof is due primarily to epithermal neutron population build-up; and said second interval substantially spans at least a portion of only the die-away of the epithermal neutron population and substantially only between the fast neutron pulses.

Features and advantages of the invention will be apparent from the following description.

Figure 1 is a schematic illustration showing a well logging system for performing earth formation porosity measurements in a borehole according to the present invention;

Figure 2 is a graphical representation showing a burst of fast neutrons, the resulting normalized

time distributions of epithermal neutrons in adjacent earth formations having porosities of 2% and 38% and the preferred timing gates for measuring the ratios thereof;

Figure 3 is a graphical representation showing the build-up/die-away ratios vs. porosity of measurements produced using the gates shown in Figure 2; and

Figure 4 is a graphical representation illustrating the composite epithermal neutron population decay curve and time gates according to one embodiment of the present invention.

With reference to the drawings, the new and improved method for epithermal neutron porosity measurements according to the present invention will be described. Figure 1 shows schematically a well logging system suitable for performing the present invention. As shown therein, a well borehole 10 is filled with a borehole fluid 11 and penetrates the earth formation 20 to be investigated. A downhole well logging sonde 12 is suspended in the borehole 10 by means of a conventional armored logging cable 13, in a manner known in the art. Cable 13 provides for raising and lowering the sonde through the borehole and contains one or more electrical conductors 16 for communicating between the sonde 12 and a surface electronics package 17, as desired.

A sheave wheel 14 at the surface, over which cable 13 passes, is electrically or mechanically coupled, as indicated by dotted line 15, to a well logging recorder 18. Recorder 18 may comprise an optical recorder or magnetic tape, or both, as known in the art, for recording the measurements made by the downhole sonde 12 as a function of the depth in the borehole of the sonde 12.

In the downhole sonde 12, a neutron generator 21, such as a deuterium-tritium accelerator, is supplied by a high voltage power supply 22 with high voltage (approximately 100 kilovolts) for its operation. Control and telemetry electronics 15 supply control signals to the neutron generator 21 and the high voltage supply 22, and telemeter information measured by the instrumentation in the downhole sonde 12 to the surface by means of the logging cable 13.

Longitudinally spaced from the neutron generator 21 is an epithermal neutron detector 23. In the preferred embodiment, detector 23 is a pressurized He counter and is wrapped with a cadmium shield to shield it from and absorb thermal neutrons. Detector 23 therefore detects those epithermal neutrons from the borehole and adjacent earth formations which result from moderation of the fast 14 Mev neutrons emitted by neutron generator 21. A neutron shielding material 28 having a high density matter content or large scattering cross-section is interposed between the neutron generator 21 and the detector 23, in order to prevent direct irradiation of the detector by neutrons emitted by the neutron generator 21.

Upon activation of the neutron generator 21, a relatively short burst or pulse of neutrons (see

Fig. 2) is initiated and emitted into the well borehole 10, borehole fluid 11, and into the earth formations 20 being investigated. By a "short" burst is meant that the duration of the burst is short with respect to the epithermal decay time constant. At the same time the burst should not be so short as to adversely affect the performance or output of the neutron generator. For example, in a typical epithermal application with existing neutron generators, the pulse would be of the duration, but not be much shorter than, about five or six microseconds. Such bursts, in this example, would then have a repetition rate of about 20 kHz.

The burst of fast neutrons is moderated or slowed down to epithermal energies by elastic and inelastic scattering interactions with the nuclei of the materials in the borehole and surrounding earth formations. This creates repetitive burst of populations of epithermal neutrons in the borehole and surrounding earth formations.

For optimum sensitivity to the epithermal neutron population in the surrounding earth formations, sonde 12 is preferably equipped with means for reducing the borehole hydrogen effect. In the preferred embodiment, this is a decentralizer spring 27 which holds the sonde at the edge of the borehole. Another way to reduce the borehole effects of hydrogen would be to displace hydrogen in the borehole around the tool with something else having a low hydrogen index. This could be accomplished, for example, with an air or nitrogen filled packer in the vicinity of the detector. Although shown in an uncased borehole in Fig. 1, the tool could also be decentralized in a cased and possibly cemented borehole.

Detector 23 then detects epithermal neutrons from both the borehole and the adjacent earth formations. The detected neutrons produce voltage pulses which are supplied to the electronics section 25, counted in a digital counter, and telemetered to the surface by conductor 16 in the well logging cable 13. At the surface, the surface electronics package 17 receives the telemetered information from the downhole sonde 12 and performs calculations as further described below to determine the porosity of the adjacent earth formations 20 being investigated. The surface electronics 17 then supplies signals representative of the various measured and calculated quantities to the recorder 18 where they are recorded as a function of borehole depth.

The counting and processing of the epithermal neutron signals is done as follows (see Fig. 4). At least two time intervals, or gates, are selected as generally known in thermal neutron measurement techniques. In the preferred embodiment each gate in fact terminates before the next begins. However, it is to be understood that the term "gate" encompasses a gate which could be mathematically derived, for example by taking two gates which in fact overlap in real time, one being longer than the other, and subtracting the shorter from the longer. The resulting difference would be the non-overlapping portion, and that portion, wherever it fell relative to the repeti-

tive neutron pulses, would also be considered a gate within the terminology hereof.

In the present invention at least one of the gates preferably occurs substantially in the time interval between the repetitive pulses of fast neutrons. Depending upon whether the borehole epithermal neutron population has substantially died away, the neutrons which are detected may or may not include a borehole component, but will be representative at least of the epithermal neutron population in at least the surrounding earth formations.

As the neutrons are detected, count rate signals are generated for each gate representative of the corresponding neutron populations during those gates. These count rate signals are then combined according to relationships discussed below to obtain a measurement signal representative of the porosity of the surrounding earth formation, and the measurement signal is recorded by recorder 18 as a function of borehole depth.

When the gates occur at times following a burst of fast neutrons which are long relative to the borehole moderation time but short relative to the formation moderation time, most of the epithermal neutrons in the borehole will have been thermalized before the measurement begins. In that case, as discussed above, the epithermal neutron decay distribution may be approximated by the following relationship:

$$E(t) = A_0 e^{-\alpha t / t_s}$$

where A_0 is a constant related to the initial number of neutrons emitted during the burst and the width and shape of the burst; t_s is the slowing down (or moderation) time of the source neutrons in the formation, and is a constant. This equation, which assumes that the signals decay exponentially with time, is then solved by known techniques to provide the measurement signal.

When the gates occur at times following a burst of fast neutrons which are short relative to the borehole moderation time, the total epithermal neutron count rate expression then becomes:

$$E(t) = A_{0B} e^{-\alpha_B t / t_{sB}} + A_{0F} e^{-\alpha_F t / t_{sF}}$$

where the "B" and "F" subscripts relate to the borehole and formation components respectively. As this equation makes clear, the signals are assumed to represent the sum of two substantially independent neutron populations, one in the borehole and the other in the adjacent earth formations. Each population is assumed to decay exponentially with time at different rates.

To provide the measurement signal in this case, at least four, and preferably six, gates are taken substantially spanning the time of the borehole moderation and the formation moderation of the fast neutrons (see Fig. 4). The detected epithermal neutron populations are therefore representative of the epithermal neutron populations in both the borehole and the surrounding earth formations.

These are then combined as more fully described and explained in European specification 95900 (based on our U.S. Patent Application Serial No. 383,680) to obtain a measurement signal representative of the porosity of the surrounding earth formations.

As set forth in the '680 application, the multiple time gates are preferably, but not necessarily, contiguous and occur during an essentially continuous time interval from one until the next of the repetitive neutron pulses. The multiple time gate measurements of the counting rates are then supplied to an epithermal neutron lifetime computer. The computer computes the formation and borehole epithermal neutron lifetime components by means of an iterative separable least squares fitting of this count rate data to exponential relationships assumed to exist for the borehole and formation components of epithermal neutron decay time. By this means the computer is enabled to calculate simultaneously both the borehole epithermal neutron lifetime component and the earth formation epithermal neutron lifetime component.

As also described more fully in the '680 application, the multiple time gates may be of equal duration, or, as shown in Fig. 4, the time interval of each gate may be of subsequently greater or equal duration than its predecessor time interval. This results in intervals which are chosen such that at least two of the time intervals maximize borehole component counts and at least two others minimize borehole component counts. The aim of lengthening subsequent intervals is to statistically optimize the counting rates in each of the gates. That is, as the composite epithermal neutron population decay curve falls off, the successively wider time gates allow more counts to occur at the lower counting rate of the later time gates. The slope of the curve changes more slowly in these regions as well, so that the longer gates fall, not only where the counts are lower, but where the subsequent mathematical fitting of the curve suffers less from the more widely spaced sample points on the curve.

In the present invention, the computational techniques taught in the '680 application may also be beneficially employed to derive at least two additional measurement signals representative of the amplitude of the borehole and formation components of the respective epithermal neutron populations. And, as will be apparent from the teachings thereof, the apparent hydrogen content and relative magnitudes of both the borehole and formation regions themselves can be determined. Further, these calculations may be enhanced by utilizing borehole and formation component parameters carried forward in time from previous measurement gates.

Epithermal neutron "lifetimes" are much shorter than thermal neutron lifetimes, and the gates and the bursts of fast neutrons must therefore be very short. In the preferred embodiment the bursts of fast neutrons are short and sharp, having a width such that the burst is narrow with

respect to the decay constant being measured, such as a width of substantially five to six microseconds. The burst may be provided at a frequency of from approximately 1.0 kHz up to 20 kHz, with the gates (which may include the burst period) for each cycle occurring within these intervals.

According to the present invention, not only is the shape of the die-away curve of the epithermal neutrons related to t_d , but the shape of the epithermal neutron build-up curve (i.e., prior to die-away) is as well. That is, in low porosity formations the epithermal neutron build-up rate is slower than in high porosity formations, due to the longer slowing down time in low porosity formations (there being less hydrogen to moderate the fast neutrons to epithermal energies). As taught herein, the effects of porosity upon build-up of the epithermal neutron population can be combined with the die-away information to produce an even more sensitive measurement of porosity than either build-up or die-away alone.

Referring to Fig. 2, a graphical representation is given of a burst of fast neutrons and the resulting normalized time distributions of epithermal neutrons in adjacent earth formations having porosities of 2% and 38%. Also shown is a preferred time gaging scheme for measuring the build-up and the die-away of the resulting epithermal neutron populations. As may be seen, the first time gate has an interval substantially spanning the build-up of the epithermal neutron population and also the initial part of the die-away curve. The second time gate substantially spans the remainder of the die-away curve. The first gate thus starts several microseconds before the neutron burst and extends to about twelve microseconds thereafter. The second gate starts immediately at the end of the first and extends beyond the end of the die-away of the epithermal neutrons, for example, for about another fifty microseconds.

As shown in Fig. 2, the epithermal neutron population distribution for the 2% porosity peaks about 7 microseconds after the peak of the fast neutron burst, and then decays exponentially with 7.7 microsecond decay constant. The epithermal neutron population distribution for the 38% porosity formation shows a 5.8 microsecond decay constant. A 26% porosity formation (not shown) was observed to have a 6.2 microsecond decay constant. Although these differences are significant, they might not be adequate in themselves, depending upon tool limitations and constraints, to yield a statistically accurate porosity measurement. For example, in one trial the integrated instantaneous count rate in the 2% porosity formation (i.e., the area under the curve) was approximately 150 counts per second and that in the 38% porosity formation was about 60 counts per second.

Comparing the overlaid curves for the 2% and 38% porosity formations (Fig. 2), it will be observed that, in addition to the differences in the die-away slopes, there are also differences in the

build-up rates of the epithermal neutrons. These composite differences are quantified according to the present invention by taking the ratio of the epithermal neutron counts beginning at the burst and ending in the early part of the die-away curve (i.e., the first gate) to the counts in the latter portion of the die-away curve (the second gate). It has been found that such a ratio increases with increasing porosity, as shown in Fig. 3, since more hydrogen in the pore spaces causes the epithermal neutron population to build up faster (increasing the first gate count) and die away sooner (thereby decreasing the second gate count). For example, with the time gating arrangement shown, the resulting ratio increases about 85% between 2% and the 38% porosity formations. This is in considerable contrast to the approximately 25% change in the observed die-away or decay constant alone between the same formations. Further, the statistical formation measurements are improved since count rate data from both the build-up and the die-away of the epithermal neutron population are utilized.

As may be seen, therefore, the present invention provides numerous advantages. It provides a neutron porosity measurement method which can be adapted to many existing borehole logging tools. The porosity measurement can be made using but one detector and is substantially insensitive to the gain stability of the detector and the overall output of the neutron generator. Further, in areas of known porosity, t_d could be used to determine gas saturation of the reservoir, thus furnishing a clear distinction between gas and oil in a formation. The invention thus furnishes an accurate, sensitive, versatile, single-detector neutron porosity measurement method which is essentially lithology, salinity, shale, casing, and borehole independent.

While the methods and forms of apparatus herein described constitute preferred embodiments of this invention, it is to be understood that the invention is not limited to these precise methods and forms of apparatus, and that changes may be made therein.

Claims

1. A method of determining the porosity of earth formations in the vicinity of a well borehole passing therethrough, comprising:

(a) emitting, in a portion of the borehole substantially adjacent the formations of interest, repetitive relatively short duration with respect to a typical epithermal neutron decay time constant pulses of fast neutrons for moderation to epithermal energies by interaction with nuclei of materials in the borehole and surrounding earth formations, creating thereby repetitive bursts of populations of epithermal neutrons in the borehole and surrounding earth formations,

(b) detecting epithermal neutrons at a longitudinally spaced distance in the borehole during at least two non-overlapping predetermined time intervals comprising a first interval and a second

pect to the decay constant being measured, such as a width of substantially five to six microseconds. The burst may be provided at a frequency of from approximately 1.0 kHz up to 20 kHz, with the gates (which may include the burst period) for each cycle occurring within these intervals.

According to the present invention, not only is the shape of the die-away curve of the epithermal neutrons related to t_d , but the shape of the epithermal neutron build-up curve (i.e., prior to die-away) is as well. That is, in low porosity formations the epithermal neutron build-up rate is slower than in high porosity formations, due to the longer slowing down time in low porosity formations (there being less hydrogen to moderate the fast neutrons to epithermal energies). As taught herein, the effects of porosity upon build-up of the epithermal neutron population can be combined with the die-away information to produce an even more sensitive measurement of porosity than either build-up or die-away alone.

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As may be seen, therefore, the present invention provides numerous advantages. It provides a neutron porosity measurement method which can be adapted to many existing borehole logging tools. The porosity measurement can be made using but one detector and is substantially insensitive to the gain stability of the detector and the overall output of the neutron generator. Further, in areas of known porosity, t_d could be used to determine gas saturation of the reservoir, thus furnishing a clear distinction between gas and oil in a formation. The invention thus furnishes an accurate, sensitive, versatile, single-detector neutron porosity measurement method which is essentially lithology, salinity, shale, casing, and borehole independent.

While the methods and forms of apparatus herein described constitute preferred embodiments of this invention, it is to be understood that the invention is not limited to these precise methods and forms of apparatus, and that changes may be made therein.

Claims

1. A method of determining the porosity of earth formations in the vicinity of a well borehole passing therethrough, comprising:

(a) emitting, in a portion of the borehole substantially adjacent the formations of interest, repetitive relatively short duration with respect to a typical epithermal neutron decay time constant pulses of fast neutrons for moderation to epithermal energies by interaction with nuclei of materials in the borehole and surrounding earth formations, creating thereby repetitive bursts of populations of epithermal neutrons in the borehole and surrounding earth formations,

(b) detecting epithermal neutrons at a longitudinally spaced distance in the borehole during at least two non-overlapping predetermined time intervals comprising a first interval and a second





interval, said detected epithermal neutrons being representative of the epithermal neutron population in at least the surrounding earth formations,

(c) generating at least two count rate signals by generating, during said at least two time intervals, corresponding count rate signals representative of the corresponding said epithermal neutron populations,

d) obtaining a measurement signal representative of the porosity of the surrounding earth formations by taking a ratio of the count rate signal during said first time interval to the count rate signal during said second time interval; and

(e) recording said measurement signal as a function of borehole depth; characterised in that, in step (b), the first interval substantially spans the build-up of the epithermal neutron population and includes each said first neutron pulse whereby the count rate signal generated in step (c) in respect thereof is due primarily to epithermal neutron population build-up; and said second interval substantially spans at least a portion of only the die-away of the epithermal neutron population and substantially only between the fast neutron pulses.

2. A method according to claim 1, wherein said step of detecting epithermal neutrons during at least two predetermined time intervals further comprises detecting epithermal neutrons in a first time interval extending substantially from several microseconds before a neutron burst to substantially twelve microseconds thereafter, and in a second time interval extending substantially from the end of the first for at least another fifty microseconds.

3. A method according to claim 1 or 2, further comprising providing neutron bursts at a frequency of substantially 20 kHz.

4. A method according to claim 1, 2 or 3, further comprising reducing the borehole hydrogen effect.

5. A method according to claim 4, further comprising reducing the borehole hydrogen effect by detecting the epithermal neutrons substantially at the edge of the borehole by aid of a decentralizer means.

6. A method according to claim 1, wherein said steps are performed repetitively at a plurality of different depths in the well borehole and produce a recording of said measurement signals as a function of borehole depth.

Patentansprüche

1. Verfahren zur Bestimmung der Porosität von Erdformationen in der Umgebung eines durch diese hindurch geführten Bohrlochs, mit den Schritten:

(a) Emittieren, in einem an die interessierenden Formationen im wesentlichen angrenzenden Teil des Bohrlochs, von wiederholten Impulsen von schnellen Neutronen mit relative kurzer Dauer im Vergleich mit einer üblichen epithermischen Neutronenabklingzeitkonstanten, zur Abbremsung auf epithermische Energien durch Wechselwir-

kung mit Kernen von Materialien im Bohrloch und in umgebenden Erdformationen, wodurch wiederholte Schauer von Populationen epithermischer Neutronen in dem Bohrloch und den umgebenden Erdformationen geschaffen werden,

(b) Ermitteln von epithermischen Neutronen in einem Längsabstand in dem Bohrloch während mindestens zweier sich nicht überschneidender vorbestimmter Zeitintervalle, die ein erstes Intervall und ein zweites Intervall enthalten, wobei besagte ermittelte epithermische Neutronen repräsentativ für die epithermische Neutronenpopulation in zumindest den umgebenden Erdformationen sind,

(c) Erzeugen von mindestens zwei Zählratensignalen, indem während zumindest der letzten zwei Zeitintervalle entsprechende für die entsprechenden epithermischen Neutronenpopulationen repräsentative Zählratensignale erzeugt werden,

(d) Erhalten eines für die Porosität der umgebenden Erdformationen repräsentativen Meßsignals, indem das Verhältnis des Zählratensignals während des ersten Zeitintervalls zu dem Zählratensignal während des zweiten Zeitintervalls gebildet wird; und

(e) Aufzeichnen des besagten Meßsignals als Funktion der Bohrlochtiefe; dadurch gekennzeichnet, daß im Schritt (b) das erste Intervall sich im wesentlichen über den Aufbau der epithermischen Neutronenpopulation erstreckt und jeden schnellen Neutronenimpuls enthält, wodurch das im Schritt (c) erzeugte Zählratensignal in dieser Hinsicht hauptsächlich dem Aufbau der epithermischen Neutronenpopulation zu verdanken ist; und daß besagtes zweites Intervall sich im wesentlichen über zumindest einen Teil nur des Abklingens der epithermischen Neutronenpopulation und im wesentlichen nur zwischen den schnellen Neutronenimpulsen erstreckt.

2. Verfahren gemäß Anspruch 1, bei welchem besagter Schritt des Erfassens epithermischer Neutronen während wenigstens zweier vorbestimmter Zeitintervalle weiterhin das Erfassen epithermischer Neutronen in einem ersten Zeitintervall enthält, welches sich im wesentlichen von mehreren Mikrosekunden vor einem Neutronenschauer bis im wesentlichen 12 Sekunden danach erstreckt, und in einem zweiten Zeitintervall, welches sich im wesentlichen vom Ende des ersten Intervalls über mindestens weitere fünfzig Mikrosekunden erstreckt.

3. Verfahren gemäß Anspruch 1 oder 2, weiterhin enthaltend das Vorsehen von Neutronenschauern mit einer Frequenz von im wesentlichen 20 kHz.

4. Verfahren gemäß Anspruch 1, 2 oder 3, weiterhin enthaltend das Vermindern der Bohrlochwasserstoffwirkung.

5. Verfahren gemäß Anspruch 4, weiterhin enthaltend das Vermindern der Bohrlochwasserstoffwirkung durch Ermitteln der epithermischen Neutronen im wesentlichen an der Kante des Bohrlochs mittels eines Dezentralisierungsmittels.

6. Verfahren gemäß Anspruch 1, in welchem besagte Schritte wiederholt in einer Vielzahl von



verschiedenen Tiefen in dem Bohrloch durchgeführt werden und eine Aufzeichnung der besagten Meßsignale in Abhängigkeit von der Bohrlochtiefe erzeugen.

Revendications

1. Procédé de détermination de la porosité de formations géologiques dans le voisinage d'un forage de puits qui les traverse, consistant:

(a) à émettre, dans une partie du forage substantiellement voisine des formations considérées, des impulsions répétitives de durée relativement courte par rapport à une constante de temps d'évanouissement typique de neutrons épithermiques, de neutrons rapides pour leur modération à des énergies épithermiques par interaction avec des noyaux de matières dans le forage et des formations géologiques environnantes, créant ainsi des trains répétitifs de populations de neutrons épithermiques dans le forage et les formations géologiques environnantes,

(b) à détecter des neutrons épithermiques à une distance espacée dans la direction longitudinale du forage pendant au moins deux intervalles de temps prédéterminés ne se chevauchant pas, comprenant un premier intervalle et un second intervalle, lesdits neutron épithermiques détectés étant représentatifs de la population de neutrons épithermiques dans au moins les formations géologiques environnantes,

(c) à produire au moins deux signaux de taux de comptage en produisant, pendant lesdits au moins deux intervalles de temps, des signaux de taux de comptage correspondants représentant les populations correspondantes desdits neutrons épithermiques,

(d) à obtenir un signal de mesure représentant la porosité des formations géologiques environnantes en prenant un rapport du signal de taux de comptage pendant ledit premier intervalle de temps avec le signal de taux de comptage pendant ledit second intervalle de temps, et

(e) à enregistrer ledit signal de mesure en fonction de la profondeur du forage, caractérisé en ce que, à la phase (b), le premier intervalle couvre pratiquement l'accumulation de la population de neutrons épithermiques et contient chaque impulsion de neutrons rapides de manière que le signal de taux de comptage produit à la phase (c) par rapport à ce dernier résulte principalement de l'accumulation d'une population de neutrons épithermiques; et en ce que ledit second intervalle couvre pratiquement au moins une partie de seulement l'évanouissement de la population de neutrons épithermiques et pratiquement et seulement entre les impulsions de neutrons rapides.

2. Procédé selon la revendication 1, dans lequel ladite phase de détection de neutrons épithermiques pendant au moins deux intervalles de temps prédéterminés consiste en outre à détecter des neutrons épithermiques dans un premier intervalle de temps s'étendant pratiquement de quelques microsecondes avant un train de neutrons, jusqu'à pratiquement douze microsecondes après et dans un second intervalle de temps d'étendant pratiquement de la fin du premier pendant au moins cinquante autres microsecondes.

3. Procédé selon la revendication 1 ou 2, consistant en outre à produire des trains de neutrons à une fréquence de pratiquement 20 kHz.

4. Procédé selon la revendication 1, 2 ou 3, consistant en outre à réduire l'effet de l'hydrogène dans le forage.

5. Procédé selon la revendication 4, consistant en outre à réduire l'effet de l'hydrogène dans le forage en détectant les neutrons épithermiques pratiquement au bord du forage à l'aide d'un dispositif de décentrage.

6. Procédé selon la revendication 1, dans lequel lesdites phases sont exécutées répétitivement à plusieurs profondeurs différentes d'un forage de puits et produisent un enregistrement desdits signaux de mesure en fonction de la profondeur du forage.



* C L M S *