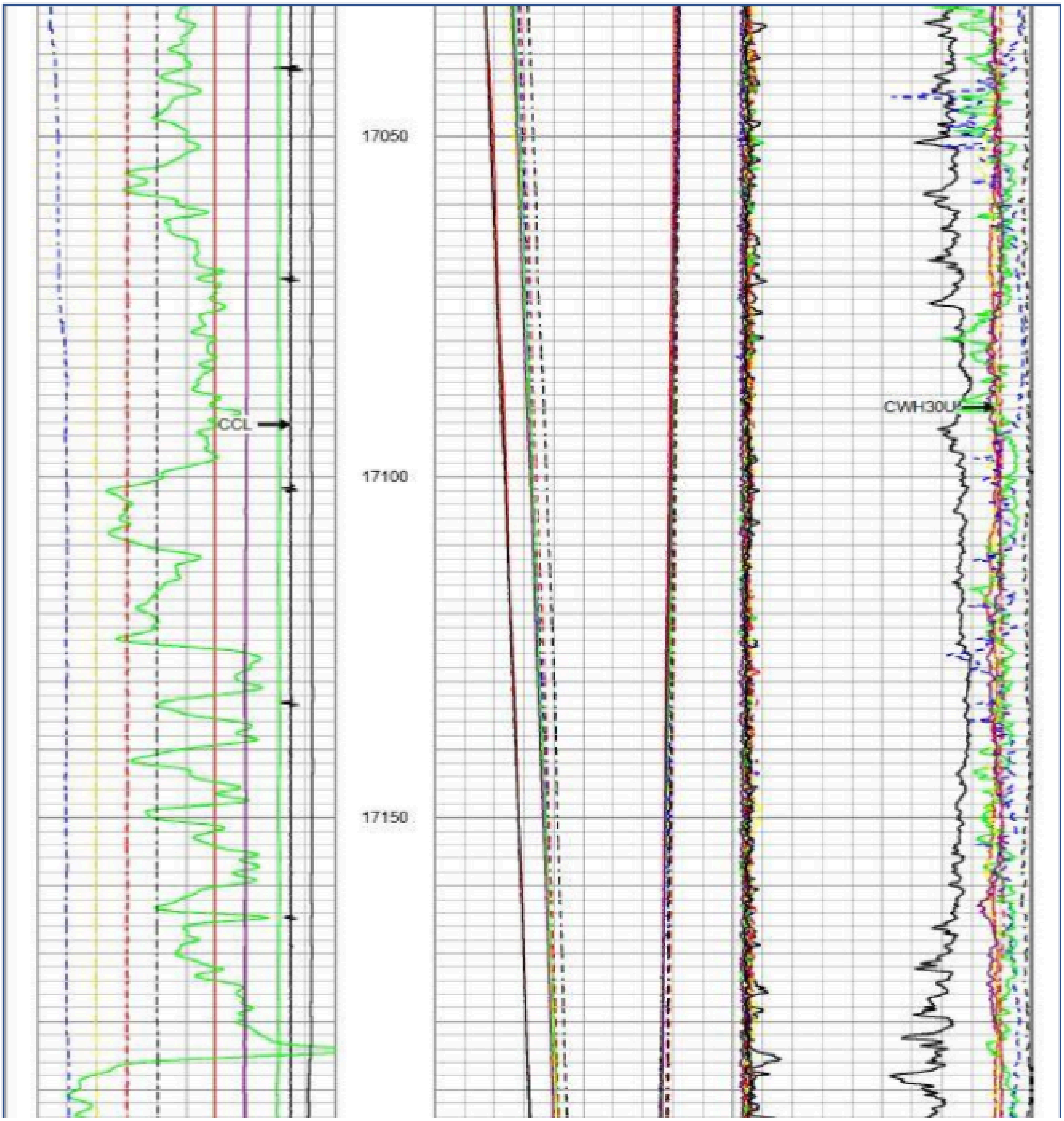
Chapter 5 - Neutron Porosity



Content

Chapter 5 - Neutron Porosity

The Neutron Porosity Tool is designed to measure the abundance of low-energy neutrons in a formation. Neutrons are emitted from a chemical radioactive source in the tool and slow down, or lose energy, as they collide with the nuclei of atoms in the formation. The primary objectives of logging the Neutron Porosity Tool are to determine formation porosity and lithology.

Because its mass is about the same as that of a neutron, the element hydrogen is very efficient at slowing neutrons to a detectable energy level. Hydrogen is mainly present in oil, gas and water, all of which occupy pore space in a formation. Therefore, the measurement made by the Neutron Porosity Tool is a function of the formation's hydrogen concentration which is largely controlled by porosity.

Applications

With knowledge of porosity (Φ) and true resistivity (RT), the fraction of pore space occupied by water (or water saturation) can be calculated using the Archie equation.

$$S_w{}^n = \frac{a}{\Phi^m} \times \frac{R_w}{R_t}$$

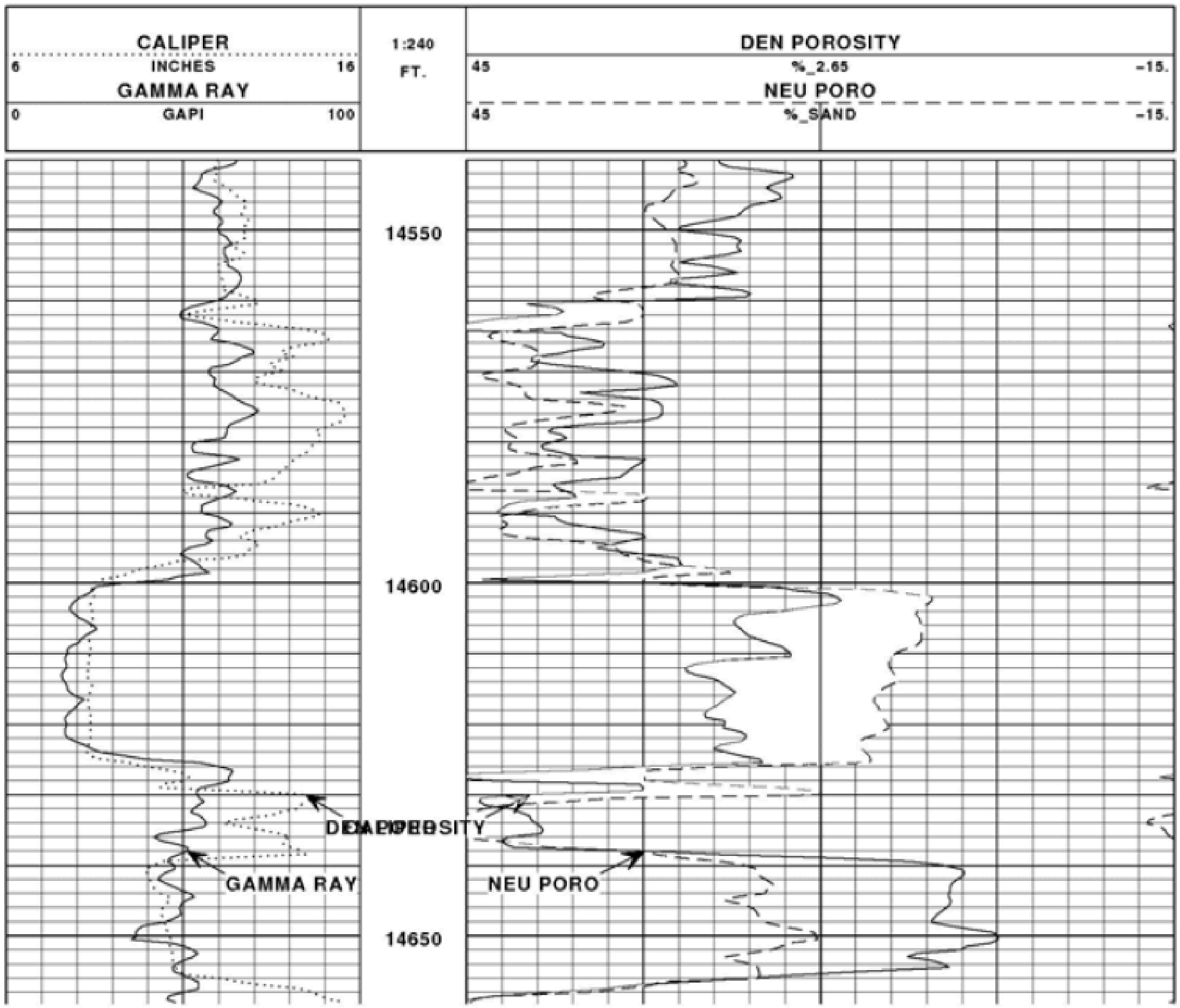
Where: S_w = water saturation of the uninvaded zone
n = saturation exponent
a = tortuosity factor
Φ = porosity
m = cementation exponent
R_w = formation water resistivity
R_t = true resistivity of the uninvaded zone

Other elements besides hydrogen present in the formation and borehole also contribute to the slowing down and ultimate capture of neutrons. The concentrations of such elements vary with rock type; therefore, the abundance of neutrons measured by the Neutron Porosity Tool is also a function of formation lithology. Knowledge of lithology is vital when predicting the production qualities of a reservoir and when designing completion programs. It also assists log analysts in determining Archie variables such as tortuosity factor (a) and cementation exponent (m) if these data are not known from core analysis or other sources.

Clay minerals—the main components of shale—contain a large amount of hydrogen within their crystalline structure that is not a part of pore fluids. The Neutron Porosity Tool is sensitive to this structurally bound hydrogen in the clay matrix as well as to any hydrogen within pore fluids. As the amount of clay minerals within a formation increases, the Neutron Porosity Tool will tend to overestimate the porosity of that formation. This is particularly true of shale which exhibits a neutron porosity that is much higher than the true porosity of the rock. Because of its sensitivity to clay minerals, the Neutron Porosity Tool's response can be used to estimate the volume of shale (VSH) of a formation when combined with density porosity or sonic porosity data.

The identification of gas-bearing formations is yet another application of the Neutron Porosity Tool (Fig. 1). Gas contains much less hydrogen per unit volume than oil or water; therefore, gas-bearing formations contain much less hydrogen than a formation of equal porosity filled with oil or water. This results in an underestimation of neutron porosity. For example, a formation containing gas exhibits a neutron porosity that is much lower than the true porosity of the formation. It may be quite difficult to identify the presence of gas on the basis of the Neutron Porosity Tool response alone, thus making it necessary to include other porosity measurements in the task.

Figure 1. Identifying gas-bearing formations (white shading) is one Neutron Porosity Tool application.



Logging Conditions

The Neutron Porosity Tool is capable of acquiring data in most well conditions, including:

- Fresh water-based mud
- Saltwater-based mud
- Oil-based mud
- Cased hole

* This document addresses only the measurement principle of the thermal neutron tool.

Physics of the Measurement

The measurement principle of the Neutron Porosity Tool relates to the energy loss experienced by neutrons as they travel from their source, through the formation and borehole, and to the detectors of the tool. Hydrogen is the most efficient element at causing this energy loss; therefore, the measurement made by the tool is a function of the amount of hydrogen present in the formation.

In a clean, shale-free formation it can be assumed that all hydrogen is present in the form of oil, gas or water, each of which occupies pore space. Accordingly, the measurement of the Neutron Porosity Tool is used to determine porosity of the formation. Understanding this principle, however, requires a closer look at how elements other than hydrogen present in the formation and borehole affect the energy loss experienced by neutrons.

Neutron Source

The Neutron Porosity Tool employs a radioactive source (for this example the source is made of americium and beryllium AmBe) to emit a continuous stream of neutrons. Americium decays to neptunium through the emission of an alpha particle (helium nucleus) and gamma radiation:

$$ {}^{241}_{95}\mathrm{Am} \rightarrow {}^{237}_{93}\mathrm{Np} + {}^{4}_{2}\mathrm{He} + \gamma(60\ \mathrm{keV}) $$

The alpha particle (i.e., helium) produced by this decay then reacts with the beryllium to produce free carbon and a neutron:

$$ {}^{4}_{2}\mathrm{He} + {}^{9}_{4}\mathrm{Be} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{1}_{0}\mathrm{n} + (5.71\,\mathrm{MeV}) $$

Figure 2. An 18.5 Curie AmBe source used in a Neutron Porosity Tool.

Only a portion of the 5.71 MeV[1] reaction energy is imparted as kinetic energy to the neutron which, as a result, travels through the borehole and into the formation at a velocity of about 107 meters per second. This "fast neutron" has an initial energy of 4.6 MeV. Fast neutrons are continuously produced by this chemical reaction at the rate of about 40 billion neutrons per second.

As fast neutrons travel out through the borehole and formation in all directions they collide with the nuclei of atoms. With each collision the neutrons lose some amount of their energy and are reduced to slower velocities (lower energy levels; Fig. 3).

Figure 3. Energy levels of neutrons.

Neutron	Energy Level
Fast	10 MeV - 1 MeV
Intermediate	1 MeV - 10 eV
Epithermal	10 eV - 0.1 eV
Thermal	<0.1 eV

[1] An electron volt (eV) is a unit of energy equal to the kinetic energy acquired by an electron passing through a potential difference of 1 volt. A neutron with an energy of 1 Mev (mega-electron volt) would have the same striking power as an electron accelerated through a 1,000,000-volt potential.

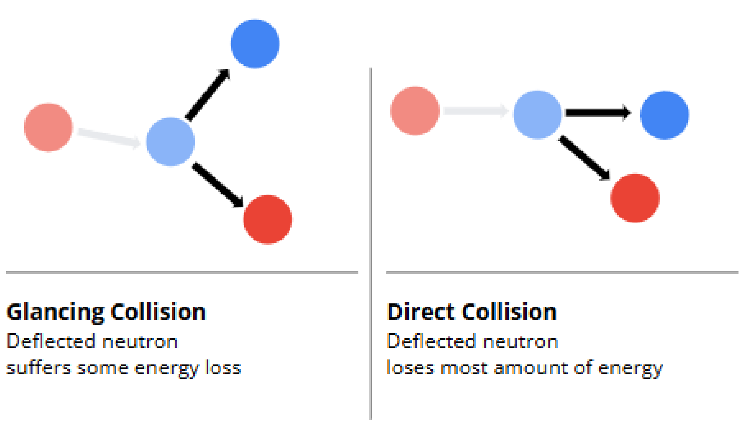
When neutrons are slowed to a thermal level they diffuse randomly until they are ultimately absorbed, or captured, by the nuclei present. The Neutron Porosity Tool is a thermal neutron tool designed to detect only those neutrons that have been slowed to thermal levels, but which have not yet been captured.

The Slowing of Neutrons

The primary mechanism by which neutrons lose energy is their elastic collision with nuclei of atoms present in the borehole and the formation. In an elastic collision the neutron collides with a nucleus and transfers some of its kinetic energy to that nucleus. Kinetic energy is conserved in this reaction as both the neutron and the nucleus are deflected away from the point of collision. As a result of the energy transferred to the struck nucleus, the deflected neutron has a lower energy level (slower velocity) than it did before the collision.

The amount of energy lost by a neutron in an elastic collision depends upon the angle of collision (Fig. 4) and the relative mass of the struck nucleus. Neutrons lose more energy in direct, or head-on, collisions than they do in glancing collisions. Also, heavy nuclei tend to scatter neutrons and absorb only a small fraction of their energy. The greatest energy loss is suffered in a collision with a nucleus of equal mass.

Figure 4. Energy loss occurs during glancing and direct (head-on) collisions with neutrons.



Because hydrogen has about the same mass as a neutron, these rules suggest that a neutron loses the most energy in a head-on collision with hydrogen. Therefore, hydrogen is the most efficient element at slowing fast neutrons to a thermal level.

Of course, not all collisions are head-on collisions and not all neutrons collide with hydrogen. Energy will be lost in any collision between a neutron and a nucleus, and the logging environment contains many elements other than hydrogen. Eventually, a fast neutron will be slowed to a thermal level even if no hydrogen is present. Nonetheless, hydrogen causes an energy loss of about 50% in each collision and is the most efficient element at slowing a neutron to a detectable thermal level. Other common rock-forming elements are less effective at slowing neutrons than hydrogen, but their influence on the Neutron Porosity Tool response cannot be ignored.

The probability that any nucleus will slow a fast neutron to a detectable thermal level is reflected by its slowing down cross section (Fig. 5). The larger the slowing down cross section of a nucleus, the more effective it is at slowing a fast neutron to a thermal level.

Figure 5. Slowing properties and capture properties of selected elements.

Element	Slowing Down Cross Section	Collisions to Reach Thermal Level (0.025 eV)	Capture Cross Section
Hydrogen	20.0	18	0.33
Boron	3.0	105	758.86
Carbon	4.8	115	0.0035
Nitrogen	10.0	130	0.075
Oxygen	4.1	150	0.0002
Sodium	3.5	215	0.4
Magnesium	3.6	227	0.0625
Aluminium	1.5	251	0.232
Silicon	1.7	261	0.1638
Chlorine	10.0	329	33.338
Iron	11.0	514	2.514

A fast neutron might experience only about 18 collisions with hydrogen before it is slowed to a thermal level of 0.025 eV. In contrast, a fast neutron might experience more than 1,000 collisions with a heavy nucleus such as that of the rare earth element cadmium before losing the same amount of energy as in 18 collisions with hydrogen.

Notice that the element chlorine (Cl), present in large concentrations in salty borehole fluids and formation water, is also quite efficient at slowing neutrons to a thermal level. Iron, present in sedimentary rocks in at least minor amounts, also has a relatively large slowing down cross section.

The Capture of Thermal Neutrons

Once a neutron is slowed to a thermal level it randomly diffuses until being captured by some nucleus. The probability that a nucleus will capture a thermal neutron is reflected by its thermal neutron capture cross section (Fig. 5). Abundant rock-forming elements (e.g., Si, O, N, Mg, Al) have relatively small capture cross sections. Boron, which may be found in trace amounts in shales, is extremely effective at capturing thermal neutrons. Chlorine is also a very effective absorber of thermal neutrons, capturing them 100 times faster than most of the other elements.

The presence of elements with large slowing down cross sections and/or large capture cross sections in sufficient concentrations greatly influences the distribution of thermal neutrons in the borehole and the formation at any given time. The larger the slowing down cross section of a formation, the shorter the distance a neutron will travel from the source before reaching a thermal level. The Neutron Porosity Tool detectors measure the thermal neutron abundance at a given distance from the source during one second of time.

Thermal Neutron Detectors

The Neutron Porosity Tool detects the abundance of thermal neutrons existing in the logging environment. The raw measurement of a thermal neutron detector is a count rate, defined as the number of thermal neutrons detected in one second (units: counts/second, or cps).

Count Rate Dependencies

For a given source strength and source-to-detector spacing, the count rate measured by a thermal neutron detector depends upon two characteristics of the logging environment surrounding the tool. These characteristics include:

1. Slowing down cross section
2. Thermal neutron capture cross section

The term "environment" is defined here to include all regions through which a neutron might pass in its travel from the source to a detector. This includes the borehole, formation matrix, and pore fluids.

Slowing Down Cross Section of the Environment

The larger the slowing down cross section of the environment, the lower the count rate. As the hydrogen concentration of a formation increases, the slowing down section of that formation increases. Therefore, the slowing down cross section is controlled in part by formation porosity. However, for different lithologies containing the same amounts of hydrogen, increased concentrations of elements with slowing down cross sections different from that of hydrogen also shorten the distance of which a neutron slows to a thermal level. A larger slowing down cross section results in a lower count rate at a detector placed some distance from the source. For example, formations with large concentrations of iron are characterized by lower count rates. Because of this influence by elements other than hydrogen, the count rate is partly a function of formation lithology.

Capture Cross Section of the Environment

The larger the thermal neutron capture cross section of the environment, the lower the count rate. Increased concentrations of elements with large capture cross sections shortens the distance that a thermal neutron travels before being captured, thus eliminating the possibility of it being detected by a detector positioned a farther distance away. Elements with very large capture cross sections such as boron, which might be present in trace amounts in shale, result in lower count rates. This again demonstrates that the count rate is partly a function of formation lithology. The presence of chlorine—with its large capture cross section (see Fig. 5)—in borehole fluids also contributes to lower count rates that are not indicative of formation characteristics. This borehole influence on the count rate must be taken into account. Furthermore, chlorine present in formation water must also be corrected for to obtain an accurate measure of formation porosity.

The Borehole Problem

Because a neutron must travel through the borehole during its journey from the source to a detector, the likelihood of a thermal neutron being detected is dependent upon borehole-related factors. These borehole factors can have a significant influence on the count rate of a thermal neutron detector, and include:

- Borehole salinity
- Borehole size
- Detector stand-off
- Borehole temperature
- Borehole pressure
- Mud weight
- Mudcake thickness

Borehole Salinity

An increase in the salinity of the borehole fluid results in two competing effects that influence the count rate measured by a thermal neutron detector. These effects are:

1. Added NaCl increases the thermal neutron capture cross section of the borehole fluid.

2. Added NaCl decreases the hydrogen concentration within the borehole fluid.

The second of these two competing effects predominates, resulting in count rates that are significantly influenced by borehole salinity. Fast neutrons emitted from the source interact immediately with the nuclei of atoms present in the borehole fluid. Because these neutrons are not at thermal energy levels so close to their source, they are not greatly influenced by the capture properties of the borehole fluid. They are, however, significantly affected by the decrease in hydrogen concentration as borehole salinity increases. Overall, an increase in borehole salinity results in an increase in the count rate.

Borehole Size

Borehole size also has an influence on the count rate. The larger the hole size, the larger the volume of borehole fluid (and, therefore, hydrogen) that neutrons must pass through, resulting in lower count rates. The effect of hole size on the count rate is compounded in situations where the borehole is filled with a high salinity drilling fluid.

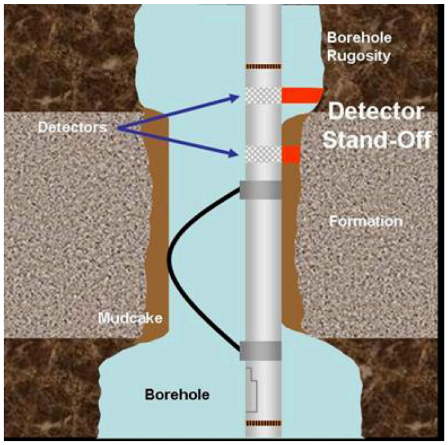
Detector Stand-Off

Another important influence on the count rate is detector stand-off. Stand-off is defined as any physical separation between a detector and the formation, and can result from a variety of contributing factors. The effects of stand-off are usually minimized by logging the Neutron Porosity Tool with a decentralizer (Fig. 6); however, even with the tool positioned against the borehole wall, other factors contributing to stand-off must be considered.

Figure 6. Bowspring decentralizer being installed on the Neutron Porosity Tool.

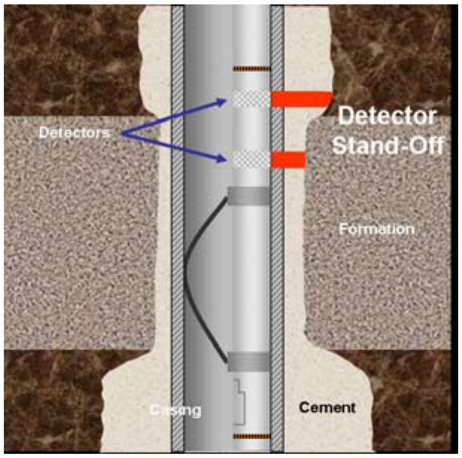
In open hole (Fig. 7), stand-off can result from the presence of mudcake and from rugose, or irregular, hole conditions. The magnitude of the influence of this stand-off depends upon the slowing down and capture properties of the material—either mudcake or drilling fluid—filling the void between a detector and the formation.

Figure 7. Neutron Porosity Tool stand-off in open hole.



In cased hole (Fig. 8), stand-off is created by the presence of casing and the cement sheath surrounding casing. The slowing and capturing properties of casing and cement, as well as their respective thicknesses, determine the magnitude of their effects on the count rate.

Figure 8. Neutron Porosity Tool stand-off in cased hole.

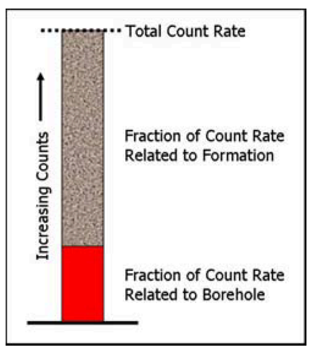


Although decentralization of the tool reduces the effects of stand-off, it does not completely eliminate them. Any residual stand-off effect requires real-time or post-processed corrections to remove its influence from the Neutron Porosity Tool response. Furthermore, additional borehole factors such as borehole temperature and pressure, mud weight, and mudcake thickness require corrections that are performed either real-time or post-processed.

Dual Detectors and the Count Rate Ratio

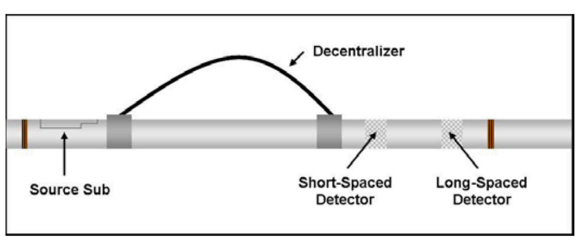
The borehole presents an interesting problem to the measurement of thermal neutrons. The slowing down cross section and capture cross section of the borehole both strongly influence the distribution of thermal neutrons in the logging environment at any instant in time. As a result, some fraction of the count rate at a thermal neutron detector is related to the borehole, while the remaining fraction is related to the formation (Fig. 9).

Figure 9. Detector count rates are related to both the borehole and the formation.



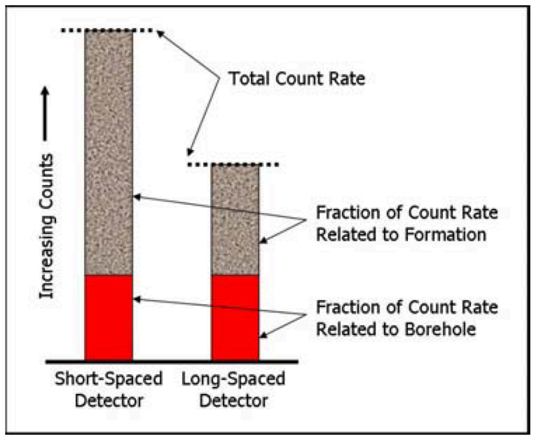
To minimize the borehole influence on Neutron Porosity Tool measurements, “dual spaced” detectors are used (Fig. 10). With this tool design two thermal neutron detectors are positioned at different distances (or spacings) from the neutron source.

Figure 10. Dual spaced detector design of a Neutron Porosity Tool.



Neutrons measured by both detectors must pass through the same borehole fluid and are exposed to very similar stand-off effects. Therefore, the fraction of the count rate that corresponds to the borehole is almost the same at both detectors. Borehole compensation is accomplished by using the ratio of the short-spaced count rate to the long-spaced count rate (SS/LS). By this method, the similar effect of the borehole on the two count rates is largely canceled (Fig. 11).

Figure 11. Dual spaced detectors allow for the compensation of similar borehole contributions to each detector's count rate.



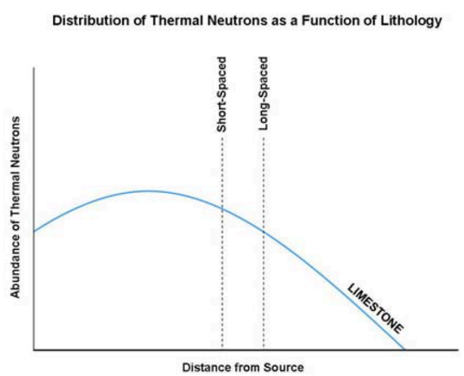
The use of the SS/LS ratio significantly reduces the borehole effect, but does not completely eliminate it. Residual borehole influence is removed from the Neutron Porosity Tool response through both real-time and post-processed environmental corrections.

Even though the borehole-related fraction of the count rates at both detectors is approximately the same, the total count rates of both detectors differ. With the borehole influence greatly reduced, this difference in count rates is related only to formation characteristics that control the distance a neutron travels before slowing to a thermal level, and the slightly greater distance it travels before being captured. These characteristics include the formation's slowing down cross section and its capture cross section. These characteristics of the formation are related to both lithology and porosity. Therefore, variations in the SS/LS ratio are primarily a function of formation lithology and porosity.

Ratio versus Lithology

The relationship between the SS/LS ratio and lithology can be illustrated by considering the distribution of thermal neutrons within a non-porous limestone (Fig. 12). This is accomplished by plotting the thermal neutron abundance during a one second detector counting interval versus distance from source. With increased distance from the source, the abundance of thermal neutrons increases as a function of the slowing down cross section of the formation. At zero-porosity there is no hydrogen present, and all slowing results form the collisions of neutrons with nuclei in the rock matrix.

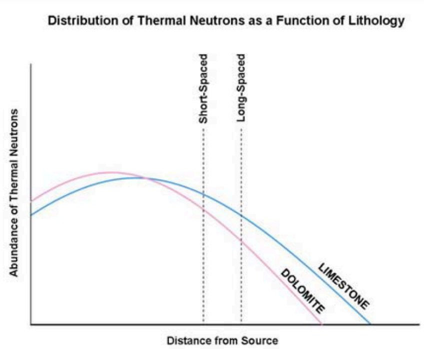
Figure 12. Distribution of thermal neutrons in zero-porosity limestone.



At some distance from the source there is a region of the formation in which the abundance of thermal neutrons is at a maximum. Beyond this maximum, the abundance of thermal neutrons decreases as they are captured by nuclei. As a function of the slowing down and capture cross sections of the formation, the short-spaced and long-spaced detectors measure different count rates, and thus, produce a certain SS/LS ratio.

Different lithologies have different abilities to slow and capture thermal neutrons, depending upon their relative concentrations of elements and their respective slowing down and capture cross sections. Formations with better slowing down properties cause neutrons to slow to a thermal level over a shorter distance of travel from their source. Dolomite (Fig. 13), for example, is more efficient than limestone at slowing neutrons to a thermal level. Therefore, the distribution of thermal neutrons in a zero-porosity dolomite is different from that in a zero-porosity limestone.

Figure 13. Distribution of thermal neutrons in zero-porosity dolomite and limestone.

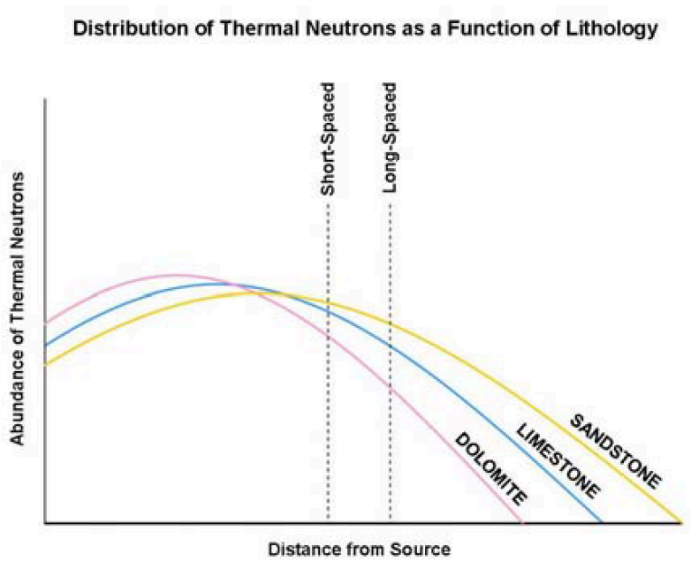


Neutrons travel a much shorter distance through dolomite before reaching a thermal level; therefore, the region of greatest thermal neutron abundance occurs closer to the source than it does in limestone. Beyond this maximum, the abundance of thermal neutrons drops off more dramatically than in limestone. The result of this change in the thermal neutron distribution is a change in the slope of the curve between the short-spaced and long-spaced detectors. The count rate at the long-spaced detector changes more dramatically than the count rate at the short-spaced detector, resulting in a higher slope. Therefore, zero-porosity dolomite is characterized by a higher SS/LS ratio than zero-porosity limestone.

Quartz sandstone is less efficient than limestone at slowing neutrons to a thermal level; therefore, the region of maximum thermal abundance occurs farther away from the source than in limestone. Neutrons travel a greater distance in sandstone before they are slowed to a thermal level. Beyond the maximum, the abundance of thermal neutrons decreases less dramatically than in limestone.

The result of this change in the thermal neutron distribution is an increase in the count rates at the two detectors as well as a change in the slope of the curve between the two detectors (Fig. 14). Zero-porosity quartz sandstone is characterized by a lower SS/LS ratio (lower slope) than zero porosity limestone.

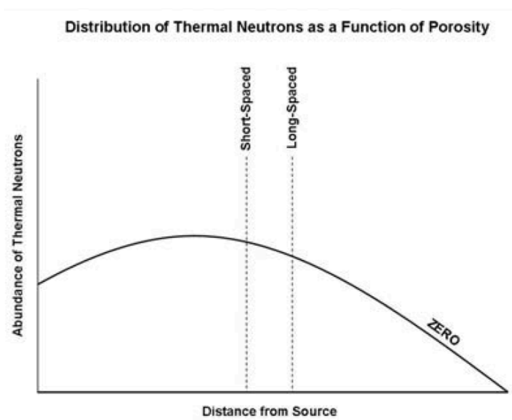
Figure 14. Distribution of thermal neutrons in zero-porosity quartz sandstone, dolomite and limestone.



Ratio versus Porosity

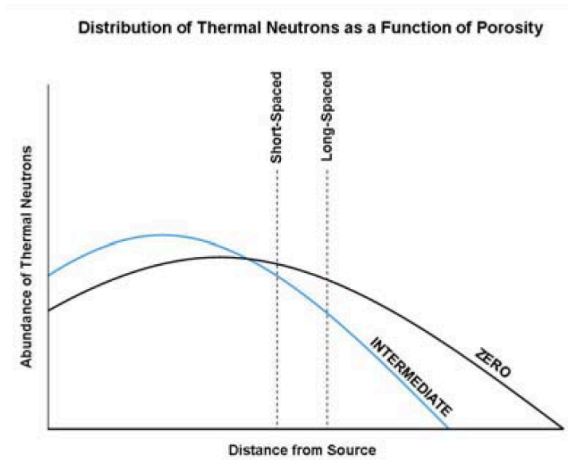
The ratio SS/LS varies with changes in lithology. However, the ratio also changes as a function of formation porosity. This can be demonstrated by first considering the distribution of thermal neutrons in a formation of given lithology and zero-porosity (Fig. 15). With increased distance from the source, the abundance of thermal neutrons increases as a function of the slowing down cross section of the formation. At zero-porosity there is no hydrogen present and all slowing results from the collision of neutrons with nuclei in the rock matrix.

Figure 15. Distribution of thermal neutrons in a zero-porosity formation.



As porosity increases, the region of greatest thermal neutron abundance occurs closer to the source (Fig. 16). This is because, with an increase in porosity, more hydrogen is present to slow the neutrons to a thermal level over a shorter distance of travel from their source.

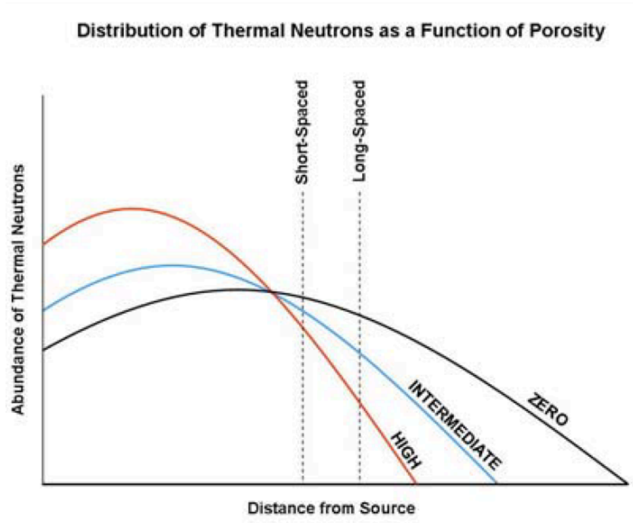
Figure 16. Distribution of thermal neutrons in an intermediate-porosity formation.



With the increase in porosity, the count rates of each detector increase; however—more importantly—the count rate at the long-spaced detector changes more dramatically than the count rate at the short-spaced detector, resulting in a higher slope. Therefore, the SS/LS ratio decrease with porosity.

With a further increase in porosity (Fig. 17), the region of greatest thermal neutron abundance occurs even closer to the source because of the increased hydrogen concentration. The result is an even more dramatic decline in the abundance of thermal neutrons between the short-spaced and the long-spaced detectors.

Figure 17. Distribution of thermal neutrons in a high-porosity formation.



The overall count rates at each detector decrease with this further increase in porosity, but the SS/LS ratio increases (higher slope). Therefore, the SS/LS ratio increases with porosity.

Standardization of Units

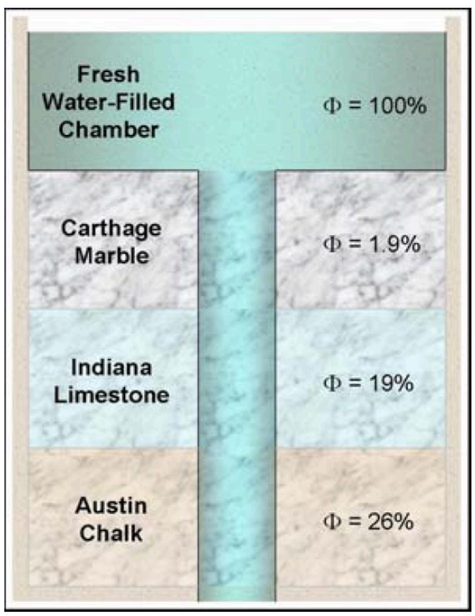
The measurement acquired by the Neutron Porosity Tool is simply a ratio of the short-spaced detector count rate to the long-spaced detector count rate (SS/LS). This ratio is not particularly useful by itself and must be converted into engineering units. Conversion of the raw SS/LS ratio to engineering units is accomplished through calibration. The calibration process also ensures that all Neutron Porosity Tool tools measure the same response in the same formation.

The SS/LS ratio measured by the Neutron Porosity Tool is not solely a function of the borehole, formation lithology, and formation porosity. Small irregularities in detector design and minute inconsistencies in detector spacings can also influence the ratio. There must be some calibration standard that allows these tool factors to be eliminated from the response.

The API Neutron Test Pit

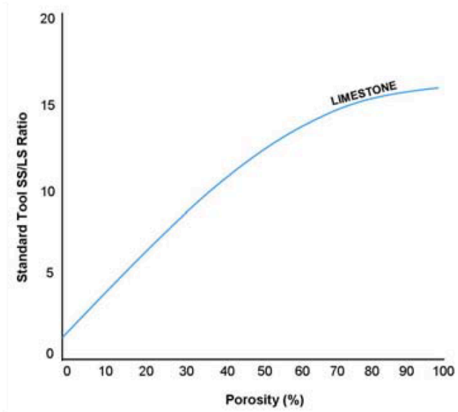
Two Neutron Porosity Tool tools logged in the same formation can exhibit different SS/LS ratios. To avoid discrepancies in measurements between tools, the American Petroleum Institute (API) prescribed a standard calibration method for neutron tools and constructed a neutron test pit at the University of Houston in 1958. The neutron test pit consists of layers of three different limestones with known porosities. Each of these layers is penetrated by a fresh water-filled borehole, and the pores of each limestone are saturated with fresh water. A service company designates a standard tool that is used for measuring the SS/LS ratios of each limestone interval in the API test pit (Fig. 18).

Figure 18. Schematic of the API neutron test pit.



With the standard tool in the API test pit, a SS/LS ratio is measured for each interval of known porosity and a water-filled chamber representing 100% porosity. A plot of the measured SS/LS ratio versus porosity yields a non-linear relationship (Fig. 19).

Figure 19. Measured SS/LS ratio versus porosity in the API neutron test pit.



The relationship between the standard tool's measured SS/LS ratio and porosity is represented by an equation of the following form:

$$\Phi = a_o + a_1 R + a_2 R^2 + a_3 R^3 + \ldots = \sum_{i=0}^{x} a_i R^i$$

Where: Φ = porosity
a_i = constant coefficients
R_i = SS/LS ratio measured by the standard tool in the API test pit
Φ = porosity

With known values of porosity and known borehole parameters from the API test pit, this equation is solved for the set of constant coefficients that relate the standard tool's measured SS/LS ratio to variations in porosity. Therefore, the purpose of logging the API test pit is to construct a transform of its measured SS/LS ratio to porosity in fresh water-filled limestone.

Neutron Porosity Tool Shop Calibration

It would not be practical for a service company to calibrate each of its neutron tools in the API test pit. However, it is necessary that each tool be calibrated in such a way that its response will be identical to that of the standard tool in the same conditions. Service companies, therefore, use their standard tool for measuring the SS/LS ratio of a calibrator. Service companies use horizontal water tanks (Fig. 20) for calibrating the response of each Neutron Porosity Tool. These fresh water-filled chambers are assigned a SS/LS ratio determined by the standard tool that was logged in the API neutron test pit.

Figure 20. Horizontal water tank used in Neutron Porosity Tool shop calibrations.

During shop calibration, the Neutron Porosity Tool is placed in this tank and a sensitivity factor (or gain) is determined that equates its measured ratio with the ratio determined by the standard tool in the same tank:

Calibrated Ratio = Sensitivity Factor × Measured Ratio

Once the calibrated ratio is known for a particular tool, then porosity can be calculated using the same equation determined for the standard tool in the API test pit.

$$\Phi = a_o + a_1 R_N + a_2 R_N^{\ 2} + a_3 R_N^{\ 3} + \ldots = \sum_{i=0}^{x} a_i R_N^{\ i}$$

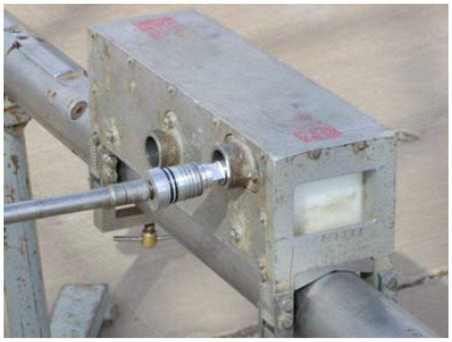
Where: Φ = porosity
a_i = constant coefficients determined for standard tool in the API test pit
R_N = calibrated SS/LS ratio of the DSNT tool

This method ensures that all Neutron Porosity Tool tools provide responses identical to that of the standard tool in the same borehole conditions.

Neutron Porosity Tool Field Verification

A verifier check block—or snow block (Fig. 21)—is used for wellsite verifications of the Neutron Porosity Tool. The SS/LS ratio of this hydrogen-rich polypropylene fixture is determined by the Neutron Porosity Tool during shop calibration and is later used only as a reference at the wellsite. The ratio of the snow block is checked immediately before and after logging to ensure that there has been no change in the tool's ability to measure an accurate calibrated SS/LS ratio.

Figure 21. Field verifier ("snow block") for the Neutron Porosity Tool.

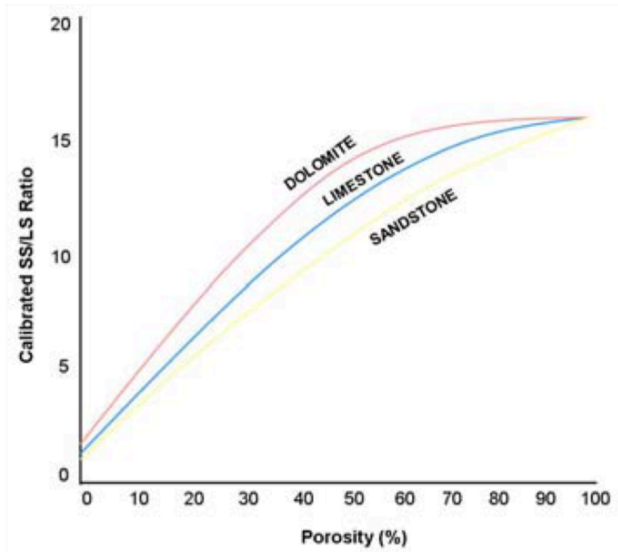


Equivalent Porosities

The SS/LS ratio of the Neutron Porosity Tool is calibrated to a fresh water-filled limestone. As porosity increases in this limestone, the SS/LS ratio increases. Of course, not all formations are limestone; therefore, it is necessary to consider the effects of lithology on the SS/LS ratio when using it to determine porosity.

Empirical data (Fig. 22) show that a given amount of porosity results in different SS/LS ratios in different lithologies. Sandstone, limestone and dolomite have different abilities to slow and capture neutrons.

Figure 22. Empirical comparisons of calibrated SS/LS ratios to porosity in different lithologies.



Suppose that a Neutron Porosity Tool is logged through a sandstone and into a limestone, both having the same porosity. As the lithology changes from sandstone to limestone, the SS/LS ratio increases. This increase in the SS/LS ratio resulting from the lithology change might be mistaken for an increase in porosity. After all, the SS/LS ratio does increase with porosity. Because of these dual dependencies, the calibrated SS/LS ratio can be used to determine an accurate formation porosity only if the lithology of that formation is known or assumed.

Common practice is to assume some lithology for the purpose of calculating porosity from the calibrated ratio. The field professional in charge of the data acquisition accomplishes this by electing a “matrix”—or neutron lithology—prior to logging.

The neutron lithologies available for calculating porosity include:

- Limestone
- Sandstone
- Dolomite
- Limey sandstone
- Limey dolomite

The resulting values of neutron porosity will only be correct for the selected lithology. If it is discovered that the true lithology of the formation does not match the assumed lithology, then neutron porosity can be recalculated from the calibrated ratio for the correct lithology.