ON SOME POSSIBILITIES FOR THE INTEGRATED STUDY OF WELLS BY PULSED NEUTRON AND ACOUSTIC METHODS

GEOPHYSICS

1969

SovietRxiv

Abstract

Full Text

UDC 550.839 + 622.32.550.83

GEOPHYSICS

Corresponding Member of the USSR Academy of Sciences M. F. Mirchink, O. L. Kuznetsov,
L. A. Sergeev, L. Z. Tslav, N. N. Deev, Yu. S. Shimelevich

ON SOME POSSIBILITIES FOR THE INTEGRATED STUDY OF WELLS BY PULSED NEUTRON AND ACOUSTIC METHODS

Limitations have been revealed in the methodological capabilities of pulsed neutron logging (PNL) ([1]) in monitoring the flooding of productive formations by low-mineralized waters, as well as formations with low porosity or with great heterogeneity. These limitations of the method can, to a considerable extent, be eliminated by the use of pulsed acoustic logging methods (PAL).

In the USSR, work on the application of acoustic logging for interpreting seismic-exploration data was begun in the 1950s ([2,3]).

Acoustic logging, like PNL, can be used to obtain information on rocks in uncased wells.

The readings of neutron methods depend on the slowing-down length of fast neutrons, the diffusion coefficient of thermal neutrons, and their mean lifetime τ. These parameters are functions of the volumetric content of hydrogen, chlorine, and a number of other elements, which, under certain conditions, makes it possible to judge the nature of saturation of reservoirs and their porosity. Naturally, the correlation relationships between the neutron and geological characteristics of the section must first be investigated.

The acoustic parameters recorded in PAL—the velocity c and attenuation α of longitudinal and transverse waves, and the degree of change in the frequency spectrum of the signal—depend mainly on the elastic and thermodynamic properties, which vary under the influence of formation pressures and temperatures, and on the structural features of the medium under study ([3,4]).

There is a fundamental possibility of changing the depth and detail of investigation of the surrounding medium by varying the wavelengths of acoustic signals (in PAL) and the recording time of radiation emission (in PNL). This feature of the methods makes it possible to study the zones of penetration of drilling-mud filtrate and the type of fluid displaced into the formation. On the basis of borehole measurements carried out by the Institute of Geology and Development of

Fig. 1

Figure 1: Fig. 1

Fossil Fuels jointly with the All-Union Institute of Exploration Technology and the Kuibyshev Scientific-Research Institute of the Petroleum Industry in the oil-bearing areas of the Kuibyshev Region and the Mangyshlak Peninsula, it appears advisable to combine PNL and PAL in solving the following problems.

1. Monitoring the flooding of productive formations. Monitoring the flooding of formations in most cases must be carried out in cased wells. A condition for the successful application of acoustic methods is the possibility of obtaining information on the properties of rocks in the presence of casing and cement. In works ([7–9]), the possibility of obtaining such information under conditions of good and partial bonding of the cement to the casing and to the rock was clarified.

In ([4–6]) it was shown that gas-bearing, oil-bearing, and water-bearing reservoirs, under identical formation conditions and reservoir properties, must differ substantially in the principal acoustic parameters (c, α). Experiments carried out under pressures up to $P \sim 650$ atm and temperatures up to $T \sim 120^{\circ}$, and theoretical calculations, show that, at equal pressures, temperatures, and porosity $K_{\text{p}} \approx 20\%$, the difference of water-

-bearing and oil-bearing sandstones in terms of compressional-wave velocities is 15-20%, and in terms of absorption 150-300% (in the frequency range 1-100 kHz). These effects depend only weakly on water salinity.

The results of the laboratory experiments were confirmed by investigations carried out in wells. Non-clayey beds, uniform in porosity, from two oil fields were studied. The porosity of the beds is 20-22%. Bed C_1 is watered by mineralized waters; bed A_3, by fresh waters. The quality of the cement over the bed intervals is good.

Fig. 1. Determination of the current position of the OWC in bed C_1 by a combination of acoustic logging and pulsed neutron-neutron logging. Electric-log curves: 1 —spontaneous potential of the well (SP); 2 —apparent resistivity (AR); radioactive logging: 3 —gamma logging (GL); 4 —neutron gamma logging (NGL); 5-6 —pulsed neutron-neutron logging (PNNL); acoustic logging: 7 —interval time; 8 —wave amplitude in the rock; 9 —oil-saturated part of the reservoir.

The geophysical characteristics of the indicated beds, including interval time, are given in Figs. 1 and 2. In well No. 206, the current position of the oil–water contact (OWC), according to the interval time Δt and the amplitude of the compressional wave A_p, is determined at a depth of 2048 m and is confirmed by PNNL data. Differentiation of the oil-bearing and water-bearing beds by interval time amounts to $\sim 20\%$, and by amplitude to $\sim 200\%$, which agrees

Fig. 2

Figure 2: Fig. 2

with the theoretical data.

In well 450, the watered intervals (Fig. 2) of bed A_3, according to the Δt diagrams, are noted at depths of 1691–1694 m and 1696–1968 m, which is indirectly confirmed by the results of production in neighboring wells. The salinity of the formation water imposes no restrictions on differentiation of the acoustic parameters of oil-bearing and watered beds, and it may be assumed that the acoustic-logging method will substantially increase the reliability of identifying the OWC under conditions of weakly mineralized and fresh waters.

In monitoring the flooding of beds, the interval-time curve apparently should be used as an auxiliary one for determining their reservoir properties. In evaluating saturation, however, the principal parameter should be the attenuation of the acoustic signal (in the form of the ratio of the amplitudes or energies of longitudinal waves through the rock, recorded at two measurement spacings).

In order to obtain more reliable geological conclusions, it would apparently be advisable to carry out, in productive intervals, repeated joint borehole measurements by acoustic logging and pulsed-neutron logging methods at different

Fig. 2. Identification of watered-out sections of bed A_3 from data of a suite of production-geophysical methods. Electric-log curves: 1—SP, 2—resistivity; radioactive logging: 3—neutron gamma logging, 4—gamma logging; acoustic logging: 5—7—interval time of wave travel through the rock, cement, and column, respectively; 8—intervals of water breakthrough into the productive bed

temperatures and pressures, which lead to different changes in the characteristics of water-bearing and oil-bearing reservoirs. Thus, for example, in one well, in accordance with (5), a change in the acoustic-log readings was noted in the OWC zone when comparing acoustic-log diagrams recorded at different temperatures in the well, which had changed as a result of cementing the annular space.

2. **Determination of the degree of isolation of productive beds during casing of wells and selection of the perforation interval.** It is known that the reliability of isolation of productive beds from adjacent water-bearing horizons and from one another depends on the quality of cementing of the annular space of wells.

Joint performance of investigations by PNNL and AL methods will make it possible to refine the position of productive horizons in the well section and to identify intervals of poor bonding of the cement sheath with the casing string and the rocks, ensuring the correct selection of perforation intervals.

As an example, Fig. 3 gives oscillograms of the wave patterns of acoustic logging for well No. 515 of the Uzen field. According to the acoustic-logging data it is

Fig. 3. Examples of oscillograms of acoustic signals recorded in a cased well.

Figure 3: Fig. 3. Examples of oscillograms of acoustic signals recorded in a cased well.

seen that the quality of cementing at the top of the productive bed (Fig. 3a) is unsatisfactory. Indeed, the interval time of arrival of the first wave packet is characteristic of a wave traveling along the string (a pipe wave), not connected with the cement. In the productive bed (Fig. 3b), the good quality of cementing is indicated by the absence of the pipe wave and by the appearance, in the first arrivals, of a wave propagating through the rocks.

Identification of gas-bearing reservoirs. Judging from the results of calculations and model studies ([1,4,6]), the joint use of pulsed neutron and acoustic methods can make the identification of gas-bearing reservoirs against the background of compacted rock varieties unambiguous. If gas-bearing and compacted beds are equally characterized by large values of τ and high readings on PNNL diagrams, then, according to acoustic-logging data, productive beds are characterized by high values of the absorption coefficients α and reduced values of the propagation velocities of elastic waves in comparison with compacted intervals. In this connection, the detection in cased wells, during the revision of old fields, of missed gas-bearing beds by comparing neutron and acoustic logging diagrams may acquire special importance. Moreover, gas-bearing beds will be identified by the intervals of the greatest discrepancies between the normalized curves of interval times Δt and the curves characterizing the intensity of secondary neutron radiation.

Fig. 3. Examples of oscillograms of acoustic signals recorded in a cased well. a –signal received in an interval of poor quality of well cementing: 1 –longitudinal wave along the string (pipe wave) $C \approx 5200$ m/sec; 2 –longitudinal wave through the rock $C \approx 3300$ m/sec; b –signal received in an interval of good quality of cementing: 1 –longitudinal wave through the rock $C \approx 3300$ m/sec, time mark 200 μsec

Institute of Geology and Development of Fossil Fuels
Academy of Sciences of the USSR

All-Union Scientific-Research
Institute of Nuclear Geophysics and Geochemistry

Received
30 IV 1969

REFERENCES

1. Yu. S. Shimelevich et al., *Fundamentals of pulsed neutron-neutron logging*, Moscow, 1964.

2. E. V. Karus, V. B. Tsukernik, *Izv. AN SSSR, ser. geofiz.*, No. 11 (1958).

3. Yu. V. Riznichenko, V. A. Glukhov, *Izv. AN SSSR, ser. geofiz.*, No. 11 (1956).

4. L. A. Sergeev, O. L. Kuznetsov, in the collection *Thermal Methods of Increasing Oil Recovery and Geothermology of Oil Fields*, Moscow, 1967.

5. L. A. Sergeev, O. L. Kuznetsov, Yu. S. Shimelevich, USSR Author' s Certificate No. 197200; *Byull. izobr.*, No. 12, 113 (1967).

6. O. L. Kuznetsov, L. A. Sergeev, *Proceedings of the VI All-Union Acoustics Conference*, 1968.

7. N. N. Deev, O. L. Kuznetsov et al., *Collection: Drilling*, No. 5, 1969.

8. P. A. Pryamov, D. V. Belokon, in the collection *Geophysical Investigations in Bashkiria*, Ufa, 1965.

9. D. M. Muir, W. A. Zoeller, *Oil and Gas J.* **65**, No. 43 (1967).

Note: Figure translations are in progress. See original paper for figures.