Cased hole

OTSK-OSZP COMBINED TOOL FOR CASING, TUBING AND ANNULUS INTEGRITY EVALUATION

SCOPE OF APPLICATION

Cased wells with OD of not more than 180 mm, through tubing with ID of not less than 60 mm, with the total thickness of the evaluated strings up to 30 mm, with the maximum bottomhole temperature of 120 °C and the maximum hydrostatic pressure of 80 MPa

FEATURES AND ADVANTAGES

The complex is designed for monitoring of casing, tubing and annulus integrity during industrial safety expert review of non-killed wells through tubing without putting the well out of operation. This complex enable:

- to perform cement placement evaluation in operating gas wells;
- to identify induced caverns in the producing gas reservoirs;
- to detect behind-the-casing and annulus accumulations of gas;
- to determine gas saturation Sg of formations;
- to create a lithological model of wells.

The downhole toolstring OTSK-OSZP consists of two modules with the possibility of both independent and combined operation. The upper module (OTSK tool) consists of a SGR probe, a scanning magnetic-pulse defectoscope, a thermometer and a pressure gauge. The lower module (OSZP tool) consists of two thermal neutron (NNL) probes disposed below the sealed fast neutron source (FNS) and three probes of wide-range induced spectral neutron gamma-ray logging (SNGR-Sh) located above the FNS.

This slim equipment was tested in oil and gas fields of Russia, Germany, Kazakhstan, etc.

OPERATION CONDITIONS

Max.pressure, MPa	80
Temperature range	from +5 °C to +120 °C
Logging cable, number of conductors	1-3
Max. length of single-conductor cable	up to 5 km
Surface equipment	
Data transmission	Manchester-2
Data transmission speed, Mbaud	1/48
Supply current of downhole tool, mA	max 250
Power supply	180–260V, 50Hz
Consumed power, W	max 30
Dimensions, length x width x height, mm:	330 x 270 x 75
Weight, kg	4
Relative humidity, %	max 98
Atmospheric pressure, kPa (mm Hg)	60-106 (450-800)

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OTSK-OSZP (48 MM TOOL SIZE) SPECIFICATIONS

OTSK Module	
Number of evaluated pipes	1; 2
Min. ID of pipes, mm	59
Max. OD of pipes, mm Single pipe logging Casing through tubing	 180 324
Min. thickness of single pipe, mm	3
Max. thickness of single pipe, mm	19
Max. total thickness of two pipes, mm	30
Basic accuracy of pipe thickness measure, mm Single pipe 2,5″ logging Single pipe 5″ logging	 ±0,3 ±0,4
Basic accuracy of pipe thickness in double-string well program, mm - tubing 2,5″ inside casing 5″ - casing 5″ through tubing 2,5″ - casing 5″ inside casing 10″	 ±0,4 ±0,7 ±0,5
Min. length of fault of "longitudinal crack" type along the pipe axis, mm: casing 2,5″ casing 5″ casing 5″ through tubing 2,5″	 20 30 70
Min. length of fault of "hole" type along the pipe axis, mm: casing 2,5″ casing 5″ casing 5″ thru tubing 2,5″	 14 30 70
Min. length of fault of "cross crack" type, mm: casing 2,5″ casing 5″	 40 80
Energy resolution of SGR probe, %	≤15
Bottom boundary of energy range in gamma ray detection by SGR probe, MeV	≤0,1
Top boundary of energy range in gamma ray detection by SGR probe, MeV	≥3
Basic relative accuracy in converting gamma-ray to pulses amplitude (integral nonlinearity of energy scale of the SGR spectrum), %	≤±3
Thermometer resolution, °C	0,01
Thermometer time constant, sec	0,5
Pressure range indication, atm	1-800
Length without centralizers, mm	≤2600
Weight, kg	≤12

OSZP Module	
Number detectors: SNGR-W NNL	 3 2
Energy resolution of SNGR probes, measured by the peak Cs^{137}, %	≤15
Bottom boundary range of gamma-ray recording of all SNGR-W probes, MeV	≤0,1
Top boundary range of low-energy spectra gamma-ray recording of all SNGR-W probes, MeV	≥ 0,6
Top boundary energy range of full spectra recording of all SNGR-W probes, MeV	≥8
Basic relative accuracy of converting gamma-ray energy to pulses amplitude (integral nonlinearity of energy scale of the SNGR spectra), %	≤±3
The range of water-saturated porosity by 2NNL method, %	1-40
Basic relative accuracy of porosity factor (POR) within 1 – 40 % does not exceed, %	4,2+2,3 (40/Kp-1)
Basic relative accuracy of gas saturation factor of formation, %	±10
Number of cement placement degrees of annular and inter-string space through tubing	4
Detection of induced caverns in productive reservoirs and their size evaluation: - Minimal local increase of well nominal radius, cm - Minimal height of caverns, cm	 5 20

Case Study No.1

OTSK-OSZP COMBINED TOOL FOR CASING, TUBING AND ANNULUS INTEGRITY EVALUATION

Challenge: Evaluate technical condition of gas well through tubings

Evaluation of well technical condition includes determining the integrity of casing and tubing, assessing the degree of filling of annular space with cement, identifying gas accumulations and clarifying the well design (position of structural elements and collar couplings).

The design of production gas well comprises a surface casing (324 mm) down to 250 m, an intermediate casing (245 mm / 900 m), a production casing (168 mm/1130 m) and tubing (89 mm/967 m). The downhole annular and inter-casing pressures are observed.

Technical condition monitoring is required without stopping and killing the well through the tubing.

Solution: OTSK-OSZP Combined Tool Logging

The downhole tool OTSK-OSZP consists of two modules with the possibility of both independent and combined operation. The upper Casing Condition Determination (OTSK) module consists of a SGR probe, a scanning magnetic-pulse defectoscope, a thermometer and a pressure gauge. The lower Annular Space Condition Evaluation (OSZP) module includes two neutron-neutron logging (2NNK) probes located below the sealed fast neutron source and three wide range spectral neutron gamma-ray logging (3SNGC-Sh) probes located above the source.

This Slim modification is used in industrial safety expert review for non-killed oil and gas wells.

OTSK-OSZP combined tool handle MID-S tool challenges, solve the problem of neutron CBL, calculate 3D lithology model and define the current saturation of reservoirs.

Result: The technical condition of well and current saturation of reservoirs was determined, 3D model was calculated

This case study covers 0-105 m and 660-1100 m intervals.

- According to MID-S, it was defined a well design, collars position of production string and tubing, packer group, as well as thicknesses of production string and tubing. No obvious defects and metal integrity failures were observed.
- 3D lithology model was built.
- The filling degree of annular space with cement was determined:
  - The cement condition behind production string is mainly evaluated as good (full filling). Cement cavities are filled with gas and water. Cement top level is at the depth of 550 m.
  - Gas accumulations behind production string are identified at the intervals 840–894 m, 933–955 m, 994–1005 m, 1018–1029 m.
  - Behind production string within 525-550 m there is a seal, caused by setting of clay sediments from drilling mud. The fluid level behind production string is 74 m. Above cementing level, gas bubbles are observed in the fluid behind production string.
  - The cement condition behind intermediate casing within the logged interval is mainly evaluated as bad or partial filling (54 % of the interval). Cement cavities are filled with gas and water. Cement top level behind intermediate casing is 6,4 m.
  - Gas accumulations behind intermediate string are detected at the intervals 6-73 m, 92–105 m, 881–896 m.
- Within 976,7–985 m a gas bubble is observed under tubing. Inside the tubing fluid with gas bubbles are detected. The source of inter-string pressure is the stored gas in reservoir.

Based on OSZP module data, oil- and gas saturation factors (Kn and Kg) are determined in the near, medium and far zones, showing saturation behavior of reservoirs in percent, gas accumulations in annular space and their location.

Key Benefits

- Studies are performed without well shut-in through tubing
- For one trip we obtain a full set of parameters
- Monitoring of technical condition of well for two inner strings simultaneously
- No geotechnical restrictions, even as to the type of wellbore fluid

Key Features

- Determining of thickness and integrity of casing, as well as their degree of wear in operation
- Specifying well design and collar locations
- Performing Neutron CBL of two strings in operating gas wells
- Locating gas accumulations behind two strings
- Defining inhibitor level behind tubing
- Identifying induced caverns in gas reservoirs
- Extra:
  - 3D lithology model building
  - current saturation and gas-saturation factors (Kg) determination
  - identifying producing and blocked intervals of reservoirs

Location: Russia

Borehole type: vertical UGS

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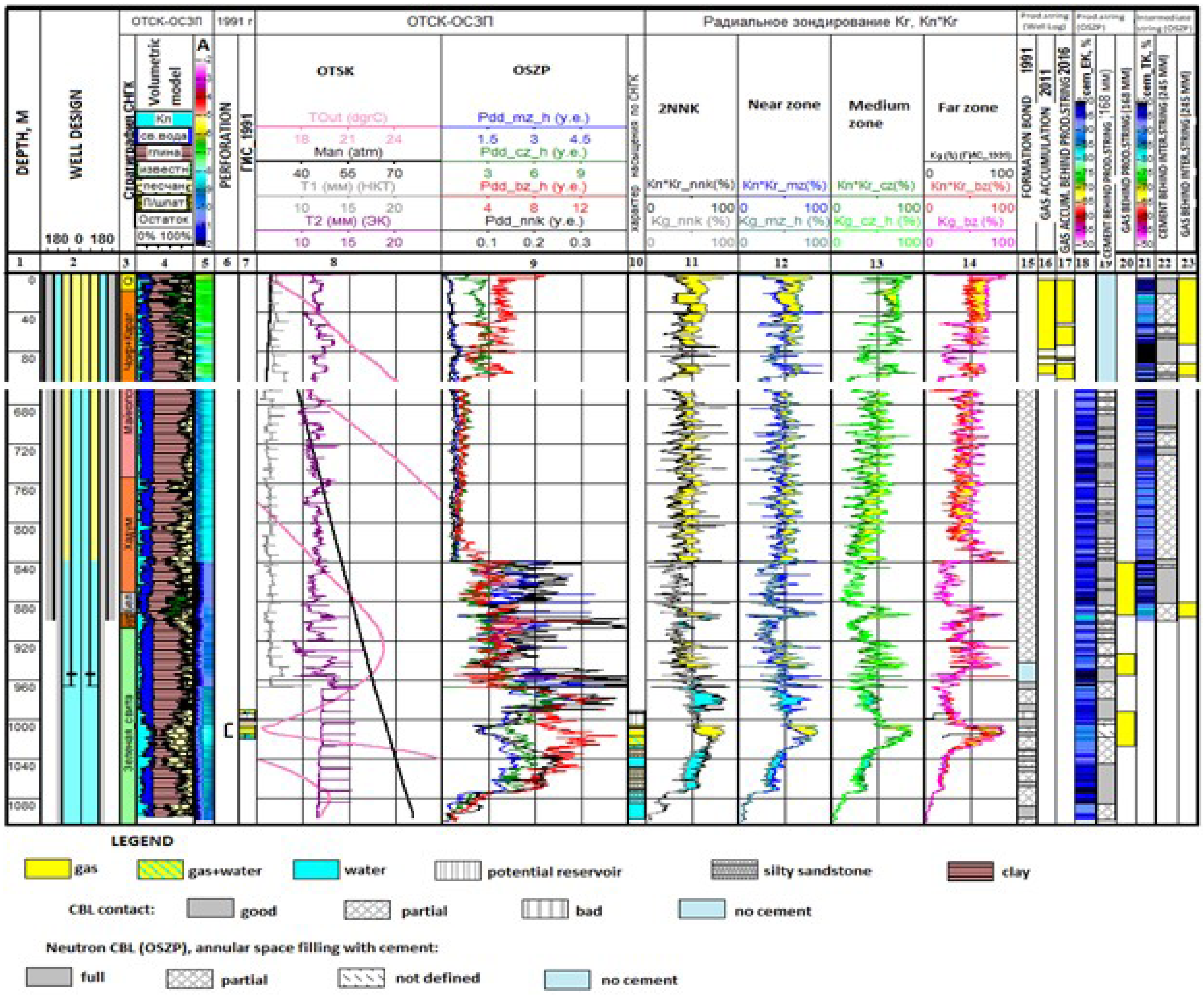
DESCRIPTION OF EXAMPLE OF OTSK-OSZP APPLICATION

Track 1 – depth scale.
Track 2 – well design, specifying wellbore, annular and inter-string space filling based on OTSK-OSZP data
Track 3 – stratigraphy based on OTSK-OSZP results
Track 4 – lithology model built on OTSK-OSZP data
Track 5 – decrement of neutron field attenuation (OSZP)
Track 6 – perforation interval by log of 1991
Track 7 – saturation Log data of 1991
Track 8 – some data of OTSK (Temperature log, pressure log, thickness of tubing and production string)
Track 9 – some data of OSZP (parameters of density deficiency and hydrogen content P(dd) for various radial zones).
Track 10 – current saturation of reservoir based on OSZP data
Track 11 – 14 – radial logging by gas saturation coefficients (Kg) and product of Kg*Kp based on OSZP data, analysis of which indicates the nature of current reservoir saturation, the presence of gas accumulations and their location.
Track 15 – CBL data for production string of 1991
Track 16 and 17 – gas accumulation intervals of annular space by logs of 2011 and 2016 correspondingly
Track 18 and 19 degree of cement filling behind production string (OSZP)
Track 20 – gas accumulations intervals behind production string (OSZP)
Track 21 and 22 – degree of cement filling behind intermediate string (OSZP)
Track 23 – gas accumulations intervals behind intermediate string (OSZP).



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Case Study No.2

The Technology of Neutron Cement evaluation

Challenge: evaluate the filling of annular space with cement in a operating gas well

The annular space filling with cement must be evaluated without shutting gas well. The use of standard CBL is not possible due to the borehole being gas-filled and having tubing.

Well parameters in the logged interval (900-2229 m): production casing 10 3/4», intermediate casing 13 3/8», liner 7», liner 4». The casing strings are cemented with Portland cement. The sediment type is saline and clay-sandy.

Solution: The technology of neutron cement evaluation

The technology is implemented with the help of digital slim multi-probe KSPRK-Sh+MID-S toolstring (OTSK-OSZP). The OTSK-OSZP tool consists of KSPRK-W and MID-S modules. SGR and three SNGR-wideband detectors methods, compensated thermal neutron method and high-sensitive thermometry are realized in KSPRK-W module. The complex enables several depths of investigation (radial logging) of neutron and gamma ray properties of the near-wellbore zone. MID-S provides evaluation of casing string integrity.

The evaluation degree of annular space placement with cement is based on the differences of neutron and gamma ray properties of cement from natural environment and it is made taking into account the properties of borehole design, columns and borehole fluid.

The technology is implemented without a cross-plot method and is based on radial logging by different physical and analytical parameters of neutron methods: density, intensity of multiple scattered neutron gamma rays, calcium content parameters, gas saturation factor, density shortage and hydrogen content coefficients. The choice of parameter is determined by the geological and technical conditions of measurements.

Result: the degree of annular space placement with cement behind two casing strings was determined, and annular gas accumulations were identified

- The degree of annular space placement with cement behind two casings: production string (900–1871,0 m), intermediate string (900–1445,3 m), 4″ liner (1756,9–2222,2 m), 7″ liner (1445,3–1756,9 m and 1871,0–2229,4 m)
- Gas accumulation intervals behind two inner casing strings (production, intermediate, 4» and 7» liners) were determined
- Inhibitor level behind 10 3/4» casing (900-1400 m) was determined
- Thicknesses of two inner strings were determined, the design and position of collar joints were specified
- Volumetric lithology model was calculated

Key benefits

- Neutron cement evaluation (express method)
- With no shut of the gas well
- Has no geological limitations
- Enable to evaluate the need to perform cementing workover without shutting down the well

Advantages:

- Obtaining the full set of parameters in one trip
- Determination of inhibitor level behind the string
- Calculating the degree of filling the annular space and inter-string space with cement for two internal casing strings, regardless of having tubing
- Detection of industry-related gas accumulations and overflows behind the two casing strings separately
- Additional evaluation of casing integrity by MID-S

Limitations:

Neutron cement evaluation does not replace the standard GR-Density Fault detector and Sonic CBL methods because it does not determine:

- The azimuthal distribution of cement behind the casing and eccentricity of string
- Cement-to-casing and cement-to-formation bond

Location: Germany

Borehole: producing, directional (up to 92° deviation)

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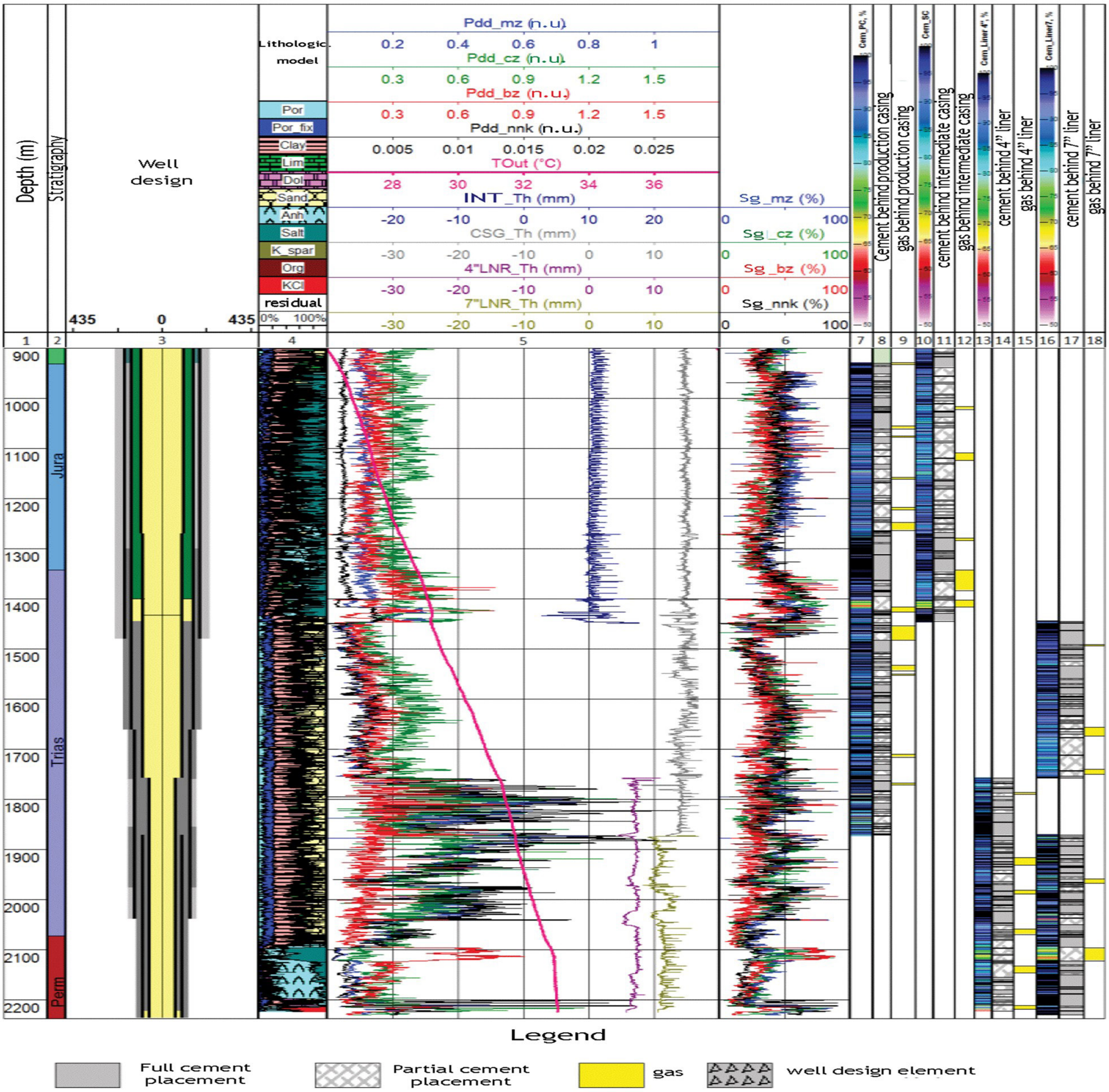

Legend:

Track 1 – depth

Track 2 – stratigraphy

Track 3 – well design according to the Customer's data. Wellbore filling: gas (yellow filling). Casing string annulus filling: Portland cement (gray filling), inhibitor (green filling)

Track 4 – Lithology model, calculated by OTSK-OSZP data based on determined analytical parameters and elements content

Track 5 – Pdd - density and hydrogen content shortage parameters according to OTSK-OSZP data by the inner zone (Pdd_nnk), near (Pdd_mz), middle (Pdd_cz) and far zone (Pdd_bz). The ratio of Pdd parameters indicates the presence of gas accumulations and its location. Other parameters: temperature (Tout), intermediate string thickness (INT-Th), production string (CSG_Th), 4» liner (LNR_Th), 7» liner (LNR_Th)

Track 6 – gas saturation coefficients (Sg) by radial zones: internal - Sg_nnk, near - Sg_mz, middle - Sg_cz and far - Sg_bz

Track 7 and 8 – the degree of cement placement behind the production string

Track 9 – gas accumulation behind production string

Track 10 and 11 – the degree of cement placement behind intermediate string

Track 12 – gas accumulation behind intermediate string

Track 13 and 14 – the degree of cement placement behind 4" liner

Track 15 – gas accumulation behind 7" liner

Track 16 and 17 – the degree of cement placement behind 4" liner

Track 17 – cement behind 7" liner

Track 18 – gas accumulation behind 7" liner

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Case Study No.3

Radial Sounding Technology for Reservoir Current Saturation Evaluation in Cased Oil and Gas Producing Wells

Challenge: evaluate saturation behavior in cased oil producing well in conditions of reservoir encroachment by fresh and saline waters

Evaluation of the current saturation in the cased oil-producing well is performed using the radial sounding technology by nuclear methods implemented in OTSK-OSZP (KSPRK-W) type tool.

The diameter of production string is 140 mm. Type of deposits is terrigenous. Borehole is filled with water. Perforation intervals are 1287-1295 m and 1302-1305 m.

Solution: application of OTSK-OSZP tool

Current saturation of reservoirs is evaluated together with determination of productivity index (So and Sg) on the basis of radial sounding (several depths of investigation) by the method of determination and analysis of density and hydrogen content deficit, which are the main diagnostic indicators in separation of gas-bearing, oil-bearing and different mineralization of water-bearing reservoirs.

Radial sounding enables to determine reservoir saturation in several zones of various depths of investigation from the borehole wall. This provides an opportunity to determine saturation, revealing not only strata, but also interstrata and annular flow of fluids.

The technology is implemented without cross-plot method.

According to MID-S data, the position of perforation intervals is specified, and the thickness of the string is determined.

Result: the current saturation and productivity factors (Sg and So) in three radial zones were determined

A volumetric lithology model (SGK and OSZP) was built, and reservoir boundaries were defined.

- Current Sg and So values were separately determined for radial zones of reservoirs, analysis of which shows that within the surveyed section reservoirs are flooded with fresh and saline water to a varying degree and partially flushed.
  - The bottom perforation interval (1302.0-1305.0 m) is producing water with gas and weak oil inflow, the seepage of which from the formation is blocked by more mobile fluid of water and gas.
  - The top perforation interval (1287-1295 m) operates poorly - the formation is strongly flushed with saline water in places.
  - In the 1216-1276 m interval, reservoirs are flooded with saline water to a varying degree. In the middle part of the interval, there are three oil-saturated reservoirs with reduced porosity and permeability properties (deep So is 34-51 %).

In annular space in the 1216-1287 m interval, water crossflow with gas So (near zone) < So (middle and far zones) is observed.

  - Above 1216 m, reservoirs are watered with fresh water, as indicated by the F(Kp)-P(dd) ratio and So similarity in radial zones, reflecting equivalent saturation of the three-phase fluid: fresh water, oil and gas, rather than oil saturation itself.
- The placement of annular space with cement is evaluated as full, in some places partial. Saturation of cavities is water with gas.
- According to MID-S, thickness production string, position of collars, perforation intervals were determined. In 1222-1231 m, 1254-1263 m no change of pipe grade, no corrosion wear of the string was detected.

Advantages:

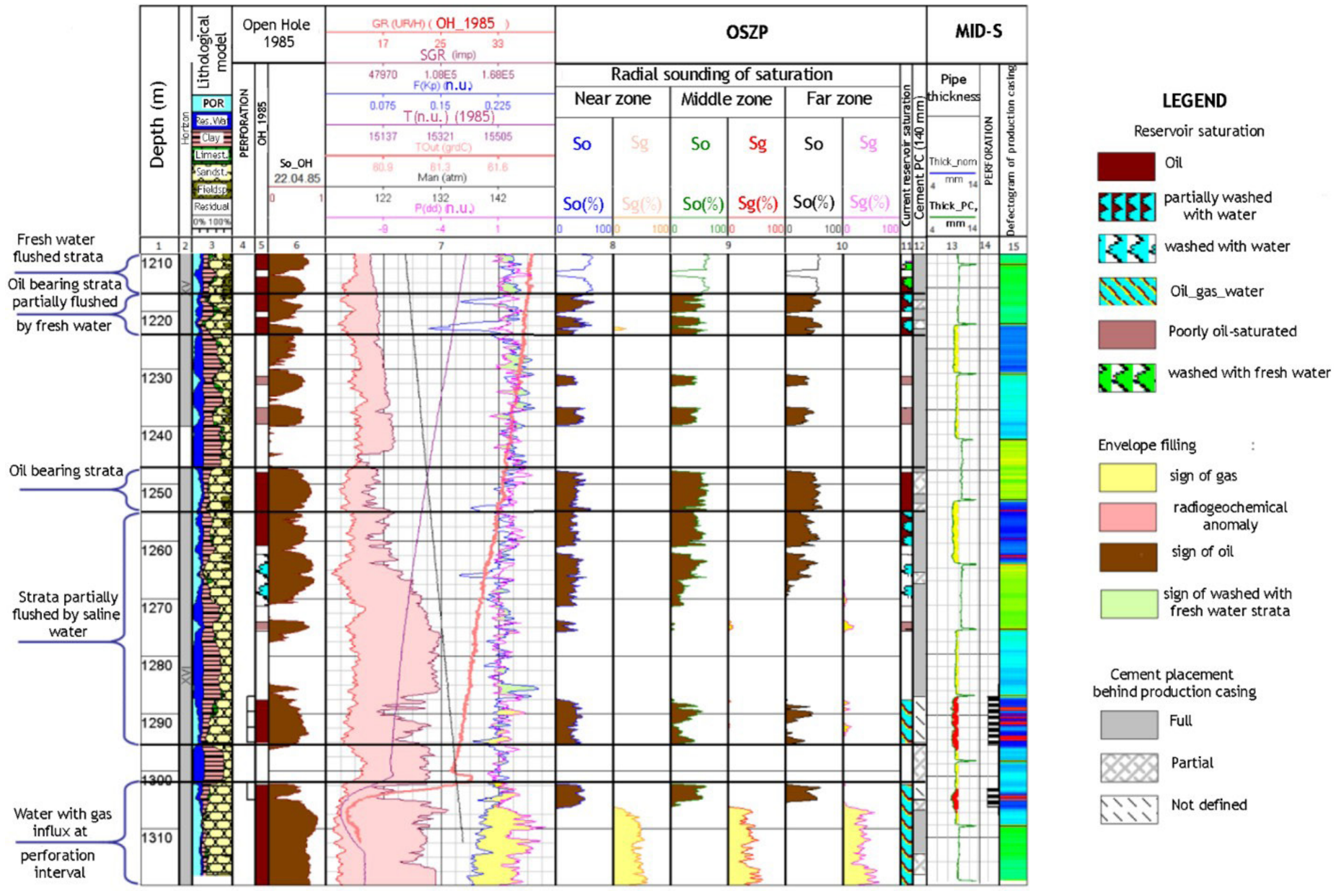
- No limitations for defining reservoir saturation by lithology and formation water salinity
- Separate identification of oil and gas saturation factors
- Possibility of radial sounding due to multi-probe, multi-method measurements in one trip
- Possibility to implement the technology irrespective of the type of wells and their design

Key Benefits

- building of the volumetric lithological model according to the data of spectrometry methods (Natural Spectral Gamma Ray, Induced Spectral Neutron Gamma Ray Wideband) and Compensated Neutron Logging
- specifying reservoirs by effective porosity
- determination of reservoir saturation and productivity indexes (Sg and So) in several radial zones from the borehole wall, regardless of reservoir fluid salinity
- identification of watering fluid by salinity
- determination of placement degree of annular space behind production casing with cement according to the results of neutron cement evaluation.

Location: Kazakhstan

Borehole: production



Track 1 – depth

Track 2 – stratigraphy stratum as per the Client data

Track 3 – lithology model calculated on SGR and OSZP data on the basis of analytical parameters and elemental composition

Track 4 – perforation interval by well logging of 1985

Track 5 – reservoir saturation according to open hole log of 1985

Track 6 – oil-saturation factor of reservoirs according to open hole log of 1985

Track 7 – Well log (GR, TM), OSZP (parameters of density and hydrogen content shortage P(dd), neutron porosity F(Kp), integral SGR, temperature log Tout, pressure gauge Man.

Track 8 – So and Sg by near zone of radial sounding (OSZP).

Track 9 – So and Sg by middle zone of radial sounding (OSZP).

Track 10 – So and Sg by far zone of radial sounding (OSZP).

Track 11– current saturation of reservoirs by radial sounding of OSZP

Track 12- cement placement degree of annular space based on OSZP

Track 13 – production string thickness (Thick_PC) by MID-S and nominal thickness (Thick_nom).

Track 14 – perforation interval by MID-S

Track 15 – defect log of production string by MID-S

Case Study No.4

Annular Space Monitoring in Operating Gas Well

Challenge: Monitoring the condition of annular space in operating gas well

Monitoring the condition of annular space of an operating gas well includes evaluating the degree of filling of the wellbore space with cement and identifying industry-related gas accumulations. Diagnostics of annular space should be performed without shutting the well (without killing and cleanup).

Well parameters in the interval of interest:

- Production string 7″
- Intermediate string 9 5/8″
- Portland-cemented casing strings (2.8 g/cm^3)
- Type of sediments - terrigenous argillaceous-carbonaceous

The problem can not be solved with standard CBL due to gas filling of the well and the presence of tubing. The ultrasonic CBL data behind the production and intermediate strings were obtained during well construction (2008).

Solution: well logging with multi-probe apparatus-and-method equipment KSPRK-Sh-48

In KSPRK-W the spectral modifications of natural spectral gamma ray (SGR), induced wideband neutron gamma ray (SNGR-W), induced thermal neutron logging (NNLt) and high-sensitivity thermometry are implemented simultaneously in one trip, enabling investigating on several depth (radial sounding) of neutron and gamma ray properties of the near-wellbore zone.

KSPRK-Sh allows to determine in three radial zones gas saturation factors, water saturated porosity, parameters of density and hydrogen content deficit, matrix density, elemental composition of studied environment.

A wide range of geological and geophysical and technical challenges are solved on the basis of KSPRK-W processing data. Testing the space condition behind the two inner casings is performed using a know-how method simultaneously with calculation of the lithological model of deposits penetrated by the well and determination of reservoir saturation type.

Advantages

- No need to stop the well
- The annular space is investigated with a 1.89″ tool in the well through tubing
- Obtaining the full set of parameters in one trip
- No geological restrictions
- Logging of two inner casing strings simultaneously

Key Benefits

- The analysis of annular space condition is based on radial probing of neutron and gamma ray properties of the near-wellbore zone and includes:
  - Determination of the degree of annular cement placement.
  - Identification of intervals of gas accumulations behind the casing
- Obtaining additional information:
  - Building of a volumetric lithological model with determination of effective porosity, shale content, etc.
  - Determination of water saturated porosity
  - Determination of reservoir saturation type and gas saturation factors in 3 radial zones of near-wellbore
  - Determination of producing, blocked gas intervals and watering intervals.
- Possibility to combine with MID-S and multi-barrier logging defectoscope

Results: changes in the annular space condition were revealed with respect to 2008

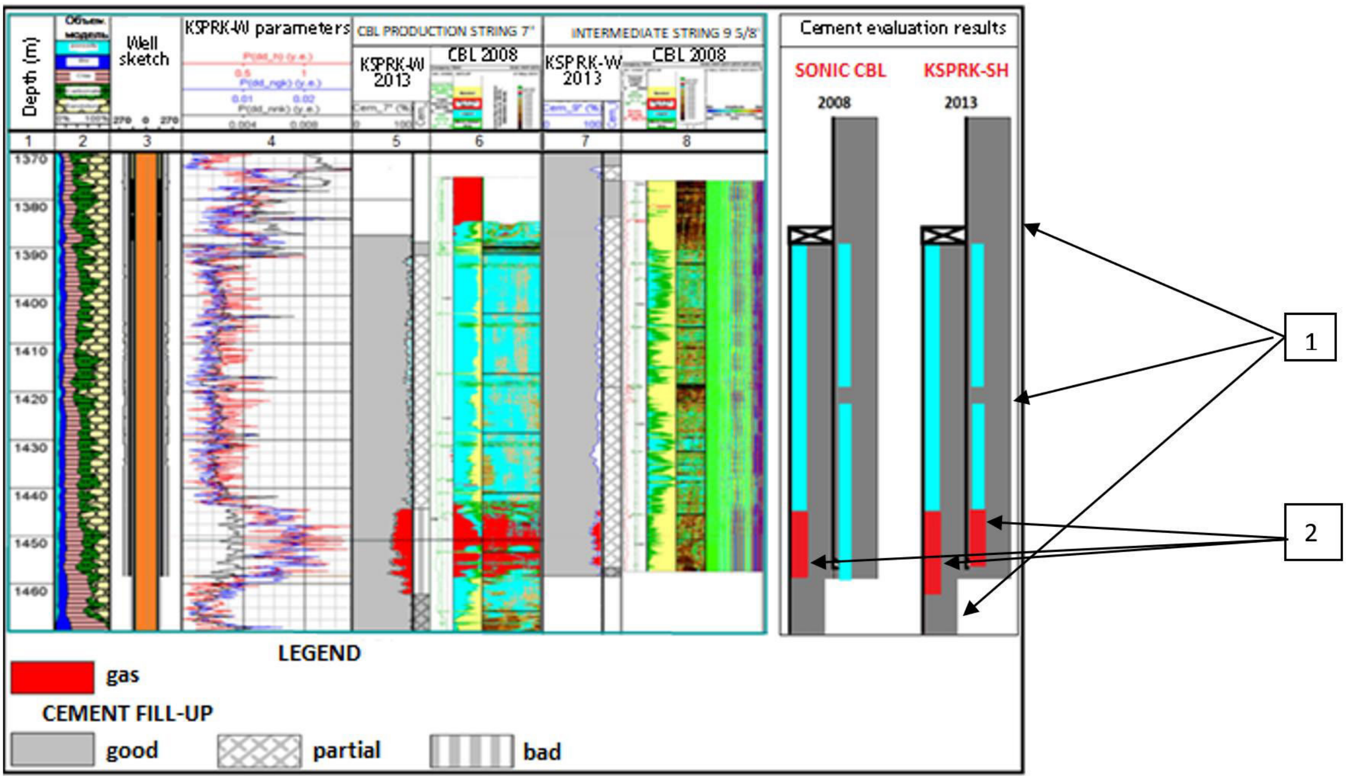
The results of KSPRK-Sh (2013) correlate well with ultrasonic CBL data (2008), which confirms the effectiveness of quick test on space condition behind the two inner casing strings simultaneously.

Behind the 7″ casing, there was a slight increase in the gas accumulation interval at 1,450 m depth and a decrease of cement top level at 1,390 m depth.

Behind column 9 5/8″, there was breaking of cement in the area of casing shoe and filling of the broken area with gas.

Location: Germany

Borehole: vertical UGS



1. Interval of High-degree cement filling of annular space
2. Interval of annular gas accumulations

Track 1 – depth

Track 2 – KSPRK-W calculated lithology model based on determined analytical parameters and elemental composition

Track 3 – Well design as per the Client data. Wellbore fill-up – gas

Track 4- parameters of density and hydrogen content deficit based on KSPRK-W data. Parameters ratio (Pdd_h, Pdd_nnk, Pdd_ngk) indicate to behind-the-casing gas accumulations and their location

Track 5 – cement placement degree behind production string (7") based on KSPRK-W data of 2013

Track 6 – ultrasonic CBL results of 2008 (cementing quality control of production string 7")

Track 7 - cement placement degree behind intermediate string (9 5/8") based on KSPRK-W data of 2013

Track 8 – ultrasonic CBL results of 2008 (cementing quality control of intermediate string 9 5/8")

On the right side of the log plot are the overall results of ultrasonic CBL in 2008 and the express test of annular space condition in 2013.

Case Study No.5

Technology for Identifying Caverns in Operating Gas Reservoirs and Estimating Their Dimensions

Challenge: identify technological caverns in operating gas reservoirs and estimate their dimensions

Formation of technological caverns in operating gas reservoirs leads to acceleration of downhole equipment wear, collapse of the reservoir and change of its porosity and permeability properties. The problem of monitoring should be solved without well shut down. KSPRK-Sh equipment can help to solve the problem.

The well is filled with gas, production string diameter is 168 mm.

Perforation interval is 741-745 m. Sediment type is terrigenous.

Solution: Technology of technological caverns detection in operating gas reservoirs and estimation of their dimensions by KSPRK-W-48 tool

The technology is based on changing the neutron and gamma ray properties of the reservoir in the radial direction from the borehole wall and is performed in an adaptive method, without cross plots. The basis of the technology is the presence of local inversion of neutron methods' readings in the geometry of spherical layers along the near zone relative to similar readings for the deeper zone.

Since the cavern is formed in the near-wellbore zone of formation, its effect on the readings of neutron methods is the stronger the smaller the radius of neutron investigation, determined by the properties of the medium under study, the type of radiation being measured and the size of the measuring probe.

The linear dimensions of the cavern represent the interval of the cavern along the wellbore and the radius average for 360° from the borehole wall.

Logging is performed in monitoring mode and before a workover to evaluate the scope of the workover.

Result: A technological cavern in an operating gas reservoir is identified and its linear dimensions are estimated

In a operating reservoir in the interval 742.8-743.5 m a cavern was detected with a maximum radius of 17 cm. The results are confirmed by the Pulsed Neutron Capture Log, which revealed a cavern in the same interval with a slightly smaller maximum radius (14 cm), which is due to the inaccuracy of cross plots dependences by PNC.

Advantages

- The problem is solved without well decommissioning in the mode of technical condition monitoring
- Allows to evaluate the necessity and scope of well workover operations
- The problem is dealt without using of cross plots but performing radial logging (several depths of investigation) of multimethod measurements

Key Benefits

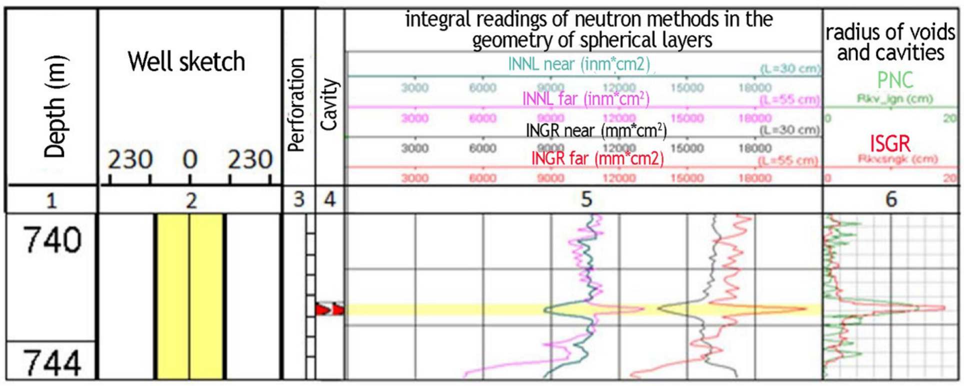
- Identifying caverns in the near-wellbore zone of gas producing reservoirs and estimating their linear size in one trip
- Identification of caverns allows predicting:
  - reservoir collapse;
  - disturbance of reservoir porosity and permeability properties;
  - accelerated wear of downhole equipment.

Key Features

- The problem is solved in the gas well for gas-filled caverns
- Reliability of identifying technologically-related caverns, as well as determining their linear dimensions, is the higher the larger the volume of the cavern and the lower the humidity of the gas filling it

Location: Russia

Borehole: producing



Track 1 – depth.

Track 2 – Well design. Wellbore filling is gas.

Track 3 – perforation interval.

Track 4 – interval of identified cavern.

Track 5 – integral readings of induced thermal neutron methods (near and far INNL) and induced neutron gamma ray methods (near and far INGR) in geometries of spherical layers

Track 6 – cavern and cavities radius. Correlation of SNGR (Spectral Neutron Gamma-Ray Log) data and PNC (Pulsed Neutron Capture) readings

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Case Study No.6

Reservoir Isolation and Current Saturation Evaluation in Oil and Gas Producing Cased Wells by complex of induced spectral neutron gamma ray (SNGR), compensated thermal neutron (NNL), natural spectral gamma ray (SGR) methods

Challenge: isolate reservoirs and evaluate saturation type in a cased oil and gas producing well

The reservoir intervals and current saturation evaluation in a cased oil and gas production well must be performed in operating well through tubing in monitoring mode.

Production string size is 168 mm, tubing size is 73 mm. The type of sediment is terrigenous. The wellbore is filled with water and gas.

Solution: application of neutron gamma-ray spectroscopy array logging tool KSPRK-W-48

The technique includes 2 stages: 1 – creating of volumetric lithology model with determination of effective porosity to identify reservoirs; 2 - evaluation of current saturation type with separation of reservoir fluid into gas, gas condensate, oil, and water with different salinity.

Volumetric model is built based on the results of elemental analysis by SGR and SNGR methods considering a priori geological-technical and geophysical information. The reservoirs are identified by boundary values of effective porosity.

Evaluation of the current saturation type of reservoir is performed together with determination of productivity coefficients (So and Sg) on the basis of radial sounding by the method of density shortage and hydrogen content analysis, which is the main diagnostic feature in separating of gas-, oil- and water-bearing reservoirs.

Radial probing enables to determine the reservoir saturation type in several zones at various depths of investigation from the borehole wall. This allows to determine saturation type, identifying not only strata, but also interstrata and cross flows of fluids.

The technology is implemented without application of cross plots.

Result: Reservoirs were identified, current saturation type and productivity coefficients (Sg and So) in three radial zones were determined

- volumetric lithologic model was created
- according to the porosity coefficients, reservoir intervals (2785,6-2787,0, 2888,0-2888,8, 2892,8-2893,6, 2897,8-2909,0 m) were identified
- saturation of BU-10-0 formation was determined as slightly gas-saturated (2785.6-2787.0 m) and gas-oil-water saturation for shaly formations (2888.0-2888.8 and 2892.8-2893.6 m)
- saturation of the perforated formation BU-10-2 is evaluated as oil with water, in the interval 2899.4-2901.6 m a gas component in the far zone (due to a decrease in reservoir pressure) is defined, in intervals 2903.2-2904.6 m and 2904.6-2908.6 m - water with residual oil (increase in the gas component due to a decrease in reservoir pressure)
- current Sg and So values were determined separately for radial zones

Advantages

- reservoirs identification taking into account properties of the studied sediments
- no restrictions in defining reservoir saturation in terms of lithological composition and salinity of formation waters
- separate determination of oil-saturation and gas-saturation factors
- possibility of performing radial probing using multi-probe, multi-methods measurements in one trip
- possibility of technology implementation regardless of well type and its design

Key Features

- creating of volumetric lithological model according to set of spectrometry methods (SGR, SNGR) and NNL
- reservoirs identification by effective porosity
- determination of reservoir saturation and productivity ratios (Sg and So) in several radial zones from the wellbore wall

Location: Russia

Borehole: producing

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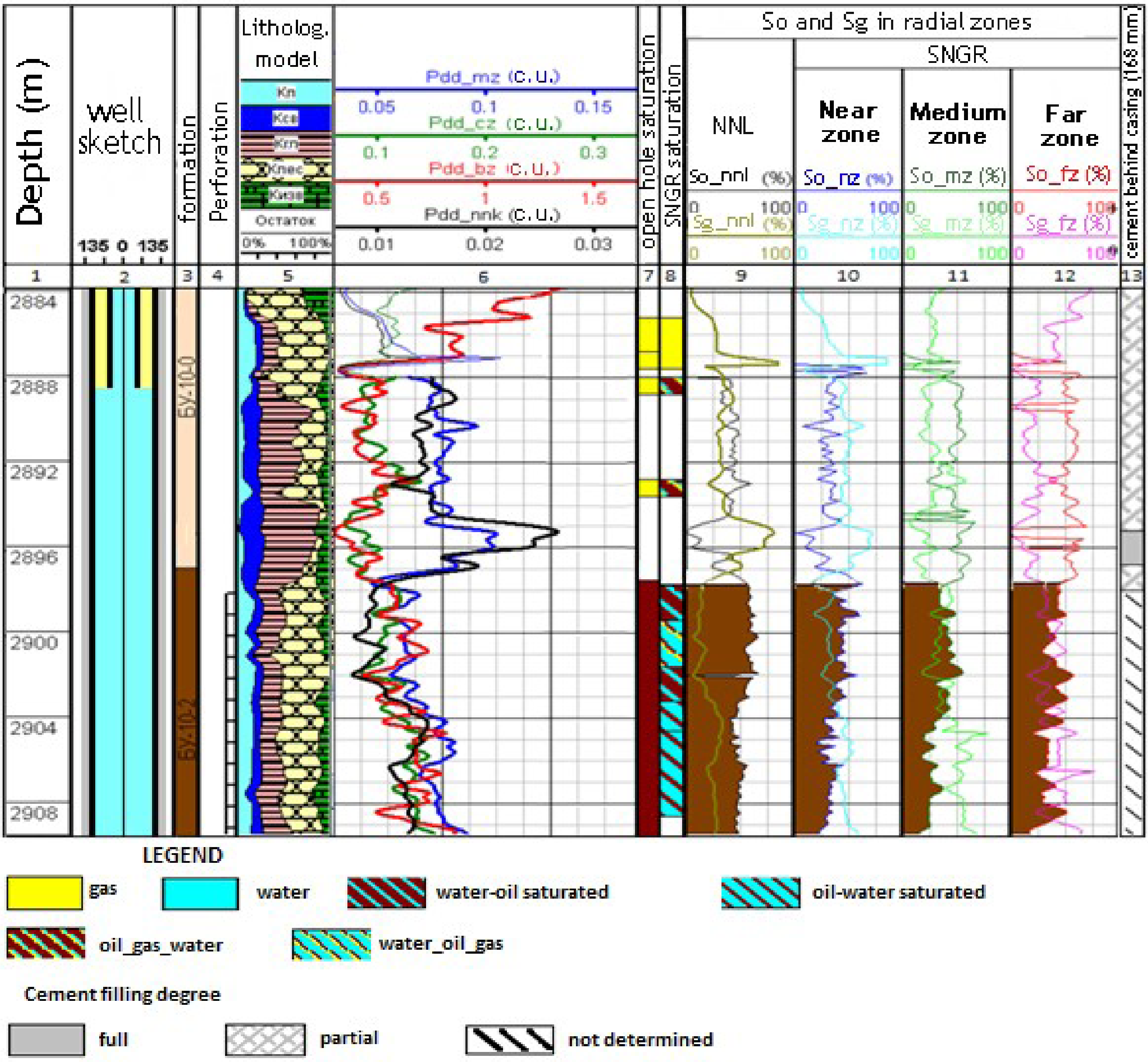

Track 1 – depth.

Track 2 – well design based on Client's data.

Track 3 – formation.

Track 4 – perforation interval.

Track 5 – lithology model, calculated on KSPRK-Sh-48 data based on determined analytical parameters and elements' composition.

Track 6 – density shortage and hydrogen content parameters (Pdd_mz, Pdd_cz, Pdd_bz, Pdd_nnk) by KSPRK-Sh-48 data

Track 7 – saturation based on well logging data when drilling

Track 8 – reservoirs identification and their saturation determination with SNGK (KSPRK-Sh-48 tool).

Track 9 – oil-saturation and gas-saturation factors (So and Sg) by NNL.

Track 10, 11, 12 – oil-saturation and gas-saturation factors (So и Sg) by SNGK for three radial zones.

Track 13 – cement behind production string (168 mm) based on KSPRK-Sh data.

Case Study No.7

The Technology of Water Inflow Monitoring in Cased Gas Wells

Challenge: perform water inflow monitoring into the perforation interval in the gas producing well

The production string diameter is 168 mm, tubing diameter is 73 mm.

To eliminate behind-the-casing flow, the well was stopped and killed, and additional perforation of the casing was performed below the main perforation interval, through which cement was injected into annular space. In the interval of 1420-1424 m a plasma impulse excitation on annular space was carried out (track 14 «excitation» red filling).

Solution: measurements by KSPRK-Sh-48 tool

Logging is carried out by KSPRK-Sh-48 tool in 2 stages:

1) when the well is set for workover, the source of water inflow is specified in the gas medium through the tubing.

2) after production string cementing and plasma impulse excitation (without tubing) the quality of cement squeeze job is controlled as to the degree of cement filling behind the casing.

The technology is implemented without applying master curves.

Result: water shutoff monitoring in perforation interval of gas production well

Stage 1 - clarification of water inflow source:

- Volumetric lithological model was built.
- The following was determined: current saturation of the reservoir by radial zones, position of gas/water contact, the degree of annular space placement with cement (Neutron cement evaluation).
- According to the data obtained, it was revealed that watering of the recovered product relates to water inflow from the lower water-bearing layer into the perforation interval through the annular space.

As indicated by:

- decreasing Sg (gas saturation) to the lower part of perforation interval up to gas/water contact in all radial zones (track 5, 1432-1442m compare to 1442-1457 m);
- Sg decrease in near distance (Kg_mz), increase on far distance (Kg_bz) (track 5, blue fill in the near zone (water) and yellow in the far zone (gas) up to gas/water contact, 1472 m).

Behind-the-casing water flow is confirmed by the results of Neutron cement evaluation (KSPRK-Sh), which revealed incomplete cement placement of annular space below the perforation interval up to the gas/water contact level. This incomplete cement placement does not affect watering of the object, as it is not a reservoir (lithomodel, track 4), but it confirms the presence of gas accumulation in the annular space.

Stage 2 – cementing quality control:

- According to the results of the second neutron cement evaluation, water shut-off by cementing of production string is done properly. Comparison of Sg before and after cementing by radial zones shows intervals of most successful cement placement (gray filling between parameters on tracks 10-12)
- The improvement of cementing quality as a result of using plasma-impulse excitation is confirmed (tracks 15-16).

Advantages

- No need to stop and kill the well when clarifying the source of water flow
- Possibility to carry out radial probing by neutron and gamma ray parameters due to multi-probe, multi-method measurements in one trip.
- Adaptive technology implemented regardless of the type of wells and their design.
- Lack of geological limitations of application.

Key Benefits

- Building of a volumetric lithological model according to the data of spectrometry methods (SGR, SNGK-Sh) and 2NNK (Neutron-Neutron Logging) and identification of reservoirs, taking into account the characteristics of the studied deposits;
- Determination of reservoir saturation behavior and gas saturation factor (Sg) in several radial zones from the borehole wall;
- Clarification of the source of reservoir watering on the basis of radial probing by Sg;
- Determination of cement filling degree in the annular space by the rapid method of Neutron cement evaluation, including in the gas environment through the tubing;
- Identification of cemented intervals.

The technology is also used to control hydraulic fracturing.

Location: Russia

Borehole: producing well

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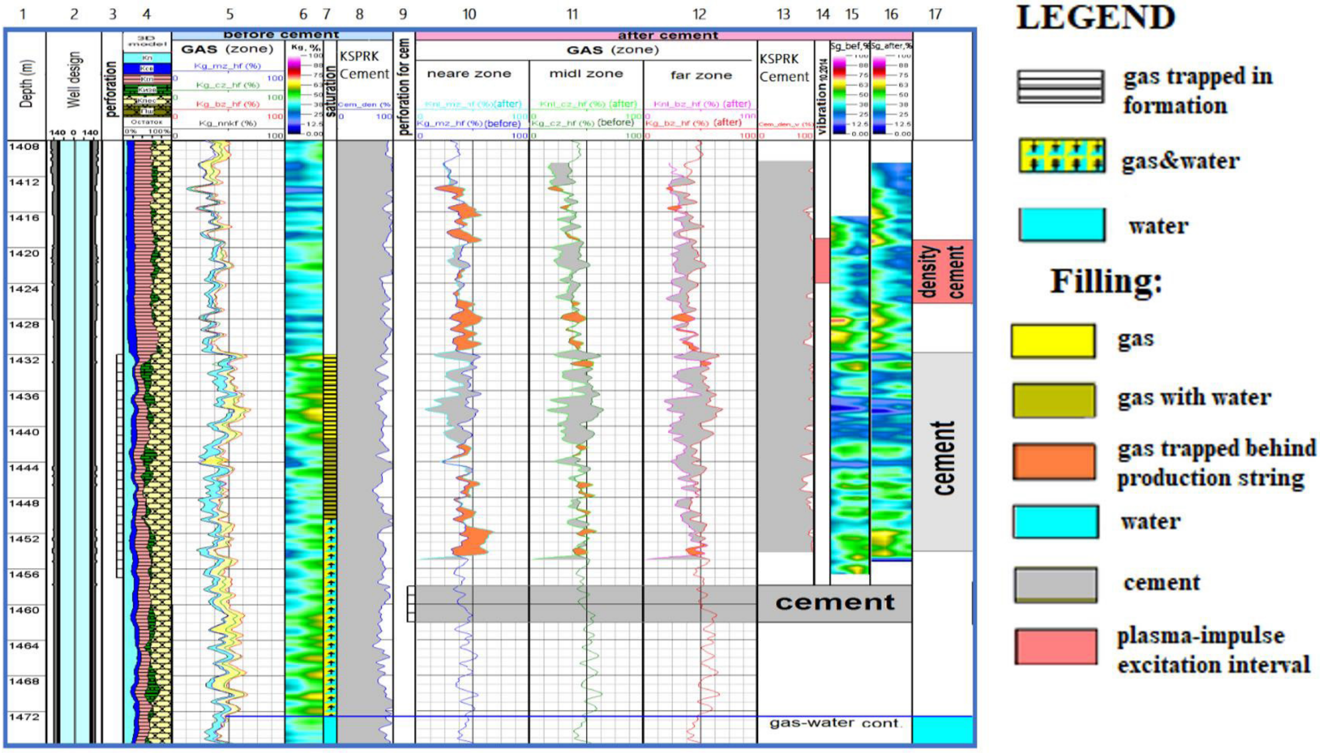

Track 1 – depth.

Track 2 – well design in workover (WO)

Track 3 – perforation interval

Track 4 – lithological model, calculated from data of KSPRK-Sh-48 based on determined analytical parameters and elemental composition in the gas well before WO operation.

Track 5 – radial sounding of the near-wellbore zone according to the current gas saturation factor (Sg) in the gas well before workover, determined by KSPRK-Sh.

Track 6 – color radial sweep of track 5

Track 7 – the current saturation behavior of the reservoir before workover

Track 8 – results of neutron cement evaluation in the gas well before WO

Track 9 – additional perforation interval for cementing of annular space

Track 10, 11, 12 – comparison of gas saturation factors for three radial zones before and after cementation and plasma-impulse excitation

Track 13 – Neutron cement evaluation results after WO operations

Track 14 – interval of plasma-impulse excitation

Track 15, 16 – color radial sweeps Sg before (15) and after the vibration treatment (16).

Track 17 – notes: interval of compacted cement behind production string (red); interval of cement-filled annular space (gray); cement injection interval; gas/water contact level.

Case Study No.8

Building of a Volumetric Rock Model and Mineralogical Model of Shales in Wells with Complex Geological and Technical Conditions

Challenge: to build a volumetric lithology model and mineralogical model of shales in open hole and cased hole in terrigenous-carbonate section and evaporite formation

The results of modeling are required to solve various geological and technical problems. Lithological models must be calculated, among other things, for an interval of cased well with limited a priori geological and geophysical data (480-850 m).

Exploration well, total depth is 1170 m. Casing: conductor (426 mm), surface casing (324 mm), production casing (178 mm). In the interval of 951-1170 m - open hole. Full set logging at the stage of drilling includes GR, Neutron GR, resistivity, sonic, density and caliper log.

Solution: use of digital multi-probe spectrometry neutron gamma-ray logging tool of KSPRK-Sh-90 type

The KSPRK-Sh-90 implements the methods of induced thermal neutron, induced neutron gamma ray, natural spectral gamma ray which enable to obtain the necessary data on the elemental composition, as well as on the neutron, gamma-ray properties of the surveyed formations.

The elemental composition of rocks according to SGR (U, Th, K) and SNGK-W (H, Cl, B, Fe, Ca, Si and other radioactive elements) allows to calculate lithological models of rocks regardless of the type of analyzed section and well design. The reliability of the calculation depends on the completeness of a priori geological and geophysical information.

Result: volumetric lithology model, and mineralogical model of shales was built

The calculated elemental composition of rocks includes the effective porosity factor (POR), fraction of bound water (Vbw), clay content (cl), sand content (sand) and feldspar sand content (sf), as well as the limestone (lime), dolomite (dol), anhydrite (anh), gypsum (gypsum), gaize (gaize), chalk (chalk), potash (carnal, KCl-potassium chloride) and rock (NaCl) salts.

The calculated mineralogical composition of shales includes glauconite, kaolinite, chlorite, montmorillonite, and mica. The model of shales is built as the total content of shale minerals 100 %.

By volumetric models:

- reservoir intervals, porosity and permeability properties were identified;
- swelling shale intervals were identified;
- stratigraphy of sediments was defined;
- the main rhythms and types of sedimentation were determined;
- intervals with increased organic material were identified.

The model was used to build a correlation section for the wells of the field.

Advantages

- versatility of building volumetric models for different types of geological sections and various types of used data
- building of volumetric models is possible with limited or even no well logs of drilling
- possibility of addressing challenges for a multistring well construction
- no need to stop the hydrocarbon well

Key Benefits

- detailed lithology differentiation of studied geological section
- mineralogical differentiation of shales
- building of correlation sections
- obtaining additional information based on the analysis of calculated volumetric model of rocks:
  - reservoirs identification and evaluation their porosity and permeability properties
  - identification of swelling shale intervals
  - evaluation of clay caps sealing of reservoirs
  - assessment of wellbore stability
  - defining of sediment stratigraphy,
  - defining main rhythms and types of sedimentation
  - identification of ores, gas hydrates and organic matter
  - determination of volumetric density, etc.

Location: Russia

Borehole: exploration

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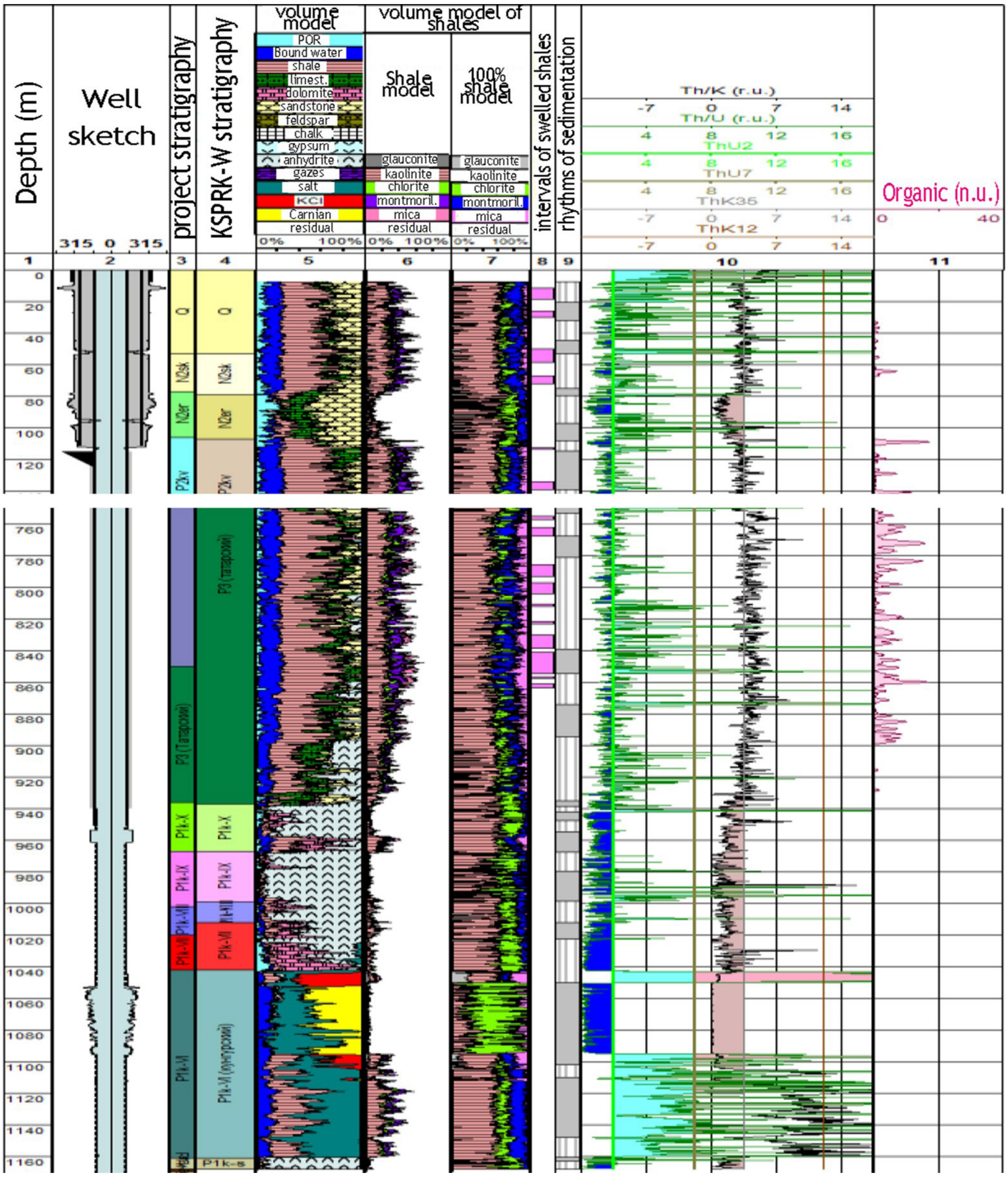

Track 1 – depth

Track 2 – well design as per the Client data

Track 3 – project stratigraphy

Track 4 – stratigraphy based on KSPRK-W data

Track 5 – volumetric lithological model calculated on the basis of the determined analytical parameters and elemental composition according to KSPRK-W data, taking into account a priori geological and geophysical information

Track 6, 7 – mineralogical model of shales

Track 8 – swelling shales intervals

Track 9 – main rhythms of sedimentation according to Th/K (SGR). Deep-water sediments are taken as the beginning of the rhythm, and shallow-water, coastal, continental sediments are taken as the end of the rhythm.

Track 10 – SGR data to identify intervals of sedimentation rhythms (Th/K) and sedimentation types (Th/U) representing deep-sea (reducing environment), marine (neutral environment), and continental (oxidizing environment) sediments

Track 11 - parameter of organic matter («organics»), which can be represented by both coaly matter and plant residues, and organogenic carbonates.

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