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MULTI-PROBE HARDWARE FOR ELECTROMETRY OF OIL AND GAS WELLS

Introduction. *The research aims at the creation of electrometry equipment capable of solving the actual problems of geophysical exploration of oil and gas wells.*

Problem Statement. *The existing equipment in Ukraine is not capable of reliably solving the problems of geophysical exploration of oil and gas wells in the conditions of Dnieper-Donets Basin.*

Purpose. *Creation and well testing of appropriate equipment with a high spatial resolution.*

Materials and Methods. *Combining potential probes that enable to restore the electric potential along the borehole axis and to solve the inverse problem with a high spatial resolution, a multi-probe resistivity logging tool has been created. Using the frequency scanning method, a multi-probe induction logging tool has been created.*

Results. *Well tests of the developed equipment in the conditions of a terrigenous cut have been carried out and its efficiency has been compared with the existing equipment in Ukraine.*

Conclusion. *The developed resistivity logging equipment has a higher resolution than LLS+LL+IL, it is also easier to operate, since it is configured as one device, instead of three separate ones. The developed induction logging equipment has the same vertical spatial resolution as the Il probe, but enables to define the geoelectric parameters of reservoir layers without involving other research methods.*

Keywords: electrometry, resistivity logging, induction logging, and oil and gas well.

In addition to many other opportunities, the borehole electric measurements enable to establish the two key points [1, 2]: how many carbohydrates are in the mine and where exactly they are in it?

The necessity to increase or, at least, to maintain the hydrocarbon yield implies the efficient use of borehole electric measurements that can define the parameters of compound geological cross sections. Such cross sections (thin-layer, anisotropic collectors [3], abnormally low-resistance collectors [4] residual oil-saturated collectors, and «false» collectors [5], etc.), as well as horizontally inclined and horizontal wells typical for current conditions the Dnieper-Donets basin (DDB) [6].

Practically, the geoelectric parameters of cross sections can be measured in two ways: by direct measurement, with the use of appropriate logging equipment, and by measurements of some average («imaginary») values, based on which the required values are determined as a result of solving the corresponding inverse problem.

Thus, using the second method, the development of a new hardware and software complex becomes an iterative task: the designed equipment must take into account the peculiarities of the algorithm for solving the inverse problem, and the algorithm for solving the inverse problem must match the structural, technical, and physical characteristics of the hardware [7, 8].

Since to evaluate the efficiency of any method of borehole electric measurements means to define the geoelectric parameters of the cross section [1, 2, 9], the requirement of high engineering and measuring characteristics of the equipment is not decisive any longer. Instead, the main question arises [10]: do the achieved engineering and measuring characteristics enable getting an exact solution of inverse problem? The second method opens a simplified way for carrying out R&D and design of the hardware component of the hardware and software complex for oil and gas well electric measurements.

The main object of the electrometric study is collector layer (reservoir bed), the main physical property of which, in terms of electrometry, is change in longitudinal conductivity (perpendicular to the borehole axis) [11, 12]. If resistivity of the near-well zone differs from that of the remote zone, such a layer is called the invaded bed. To study it, it is necessary to have several probes for measuring conductivity at different depths.

There are two practically widely used physical principles of studying the invaded beds [1, 2]: electric logging (EL) and induction logging (IL).

EL is used in wells filled with a conductive drilling fluid (resistivity <0.5 ohm · m) or a fluid with weak conductivity (0.5–5 ohm · m). IL is used in wells filled with a fluid with a weak conductivity or a nonconductive fluid (resistivity >5 ohm · m) [13]. This division is rather arbitrary, but it is used in the field of geophysical exploration of wells.

All three mentioned types of wells with different conductivity are typical for the conditions of DDB, so the creation of new electrometric equipment implies the independent design of two different complexes for EL and IL.

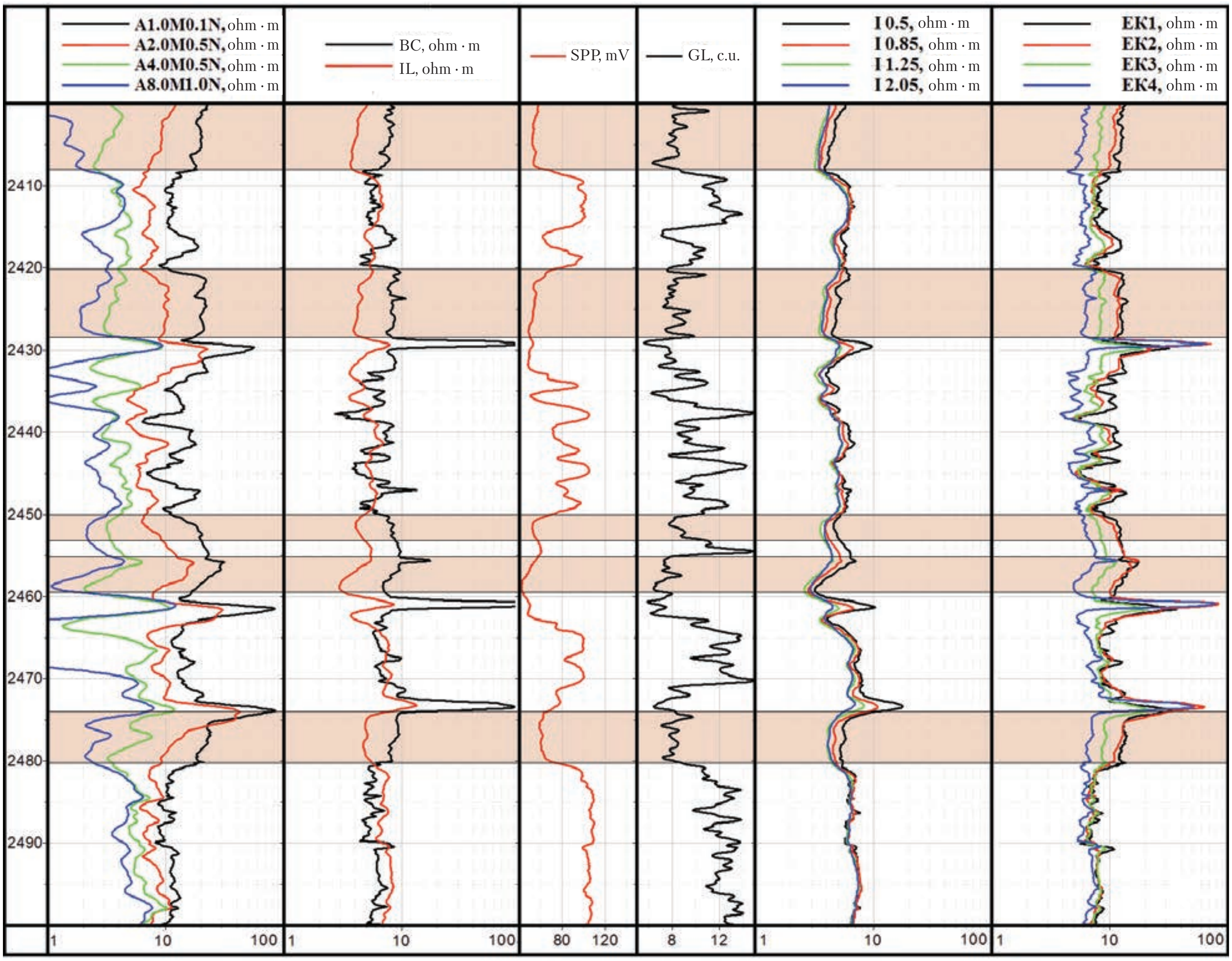
Modern means of electrometry used by Ukrainian geophysical companies of various forms of ownership are divided into the three types [14]: lateral log sounding (LLS) equipment that is a set of potential and gradient probes of different operation depths [15] having a low spatial resolution [1, 2]; EL equipment consisting of a single focused probe — lateral logging equipment (BC); equipment consisting of one IL probe or the so-called induction logging equipment (IL equipment).

In the conductive wells only LLS and LL are used; in the low-conductivity wells, LLS, LL, and IL are applied; in the non-conductive wells, only IL is used.

However, the use of LLS + LL + IL complex has significant disadvantages: in the boreholes filled with non-conductive drilling fluids one can do only one Il measurement that does not enable to establish any variation of conductivity along the layer. In the boreholes filled with high-conductivity fluids one can do only one EL measurement with a high spatial resolution, with changes in conductivity along the layer recorded with a low spatial resolution, i.e. it is impossible to establish changes in conductivity along thin formations; in the boreholes with a weak conductivity where both methods (EL and IL) can be used only two high-resolution measurements are recorded. It's not enough for determining three required parameters of thin layer formation.

It can be shown by the example of interval of well cross section (Fig. 1, drilling fluid resistivity is 0.9 ohm · m), where the first diagram features curves for LLS probes: A1.0M0.1N, A2.0M0.5N, A4.0M0.5N, and A8.0M1.0N; the second one shows LL and IL probes; the third and fourth diagrams bear curves of supplementary spontaneous polarization potential (SPP) methods and gamma-logging (GL), which help to establish invaded beds. In fact, from the whole of LLS + LL + IL only two high-resolution curves, LL and IL, are distinguished. Hence, there is a limitation on the thickness of studied invaded bed: for достовірного determination of its geoelectric parameters the bed shall be thicker than 3–4 m. Such spatial resolution was sufficient in mid-20th century, when this equipment was developed [1, 2, 13], however it is certainly not enough not only for current conditions of DDB, but also for many other oil and gas deposits. In addition, the permissible error (20% [16]) of measurement of each component of LLS + + LL + IL must be significantly reduced.

Proceeding from the above, the ultimate purpose of research is to design an multi-probe logging (more than 3 probes in each device) hard-



Comparison of results obtained by different methods for electric measurements of oil and gas wells

ware with a high spatial resolution for separate EL and separate IL measurements.

These facilities have been theoretically developed within the framework contest *R&D Projects of Institutions of the NAS of Ukraine*, in 2012, with *Geophysical Equipment Nadra* CJSC as partner organization.

The multi-probe EL hardware with a high spatial resolution has been developed due to combining normal logging devices, which enables to establish electric potential along the borehole axis [17]. This enables solving the inverse problem with a high accuracy [18] and, consequently, to measure required geoelectric parameters with a high spatial resolution (up to 1 m, along the borehole).

The multi-probe IL hardware with a high spatial resolution has been developed due to proposed method for improving measurement accuracy [19] used in four-point probe IL equipment [20, 21].

In 2014–2017, respective R&D and design works were done and full-scale mock-ups for each type of hardware were made.

For their field testing a borehole with a weak conductivity (fluid resistivity is 0.9 ohm·m) has been selected. Fig. 1 shows log sheets obtained using the multi-probe IL hardware (I0.5, I0.85, I1.25, and I2.05 curves) and the multi-probe EL hardware (EK1, EK2, EK3, and EK4 curves). The selected depth intervals correspond to the intervals in which the real fluid inflow is recorded. One can see that in each interval, the readings of the probes of each type of equipment differ, which testifies to the existence of conductivity gradient along the formation and the achievement of required spatial resolution of equipment for specified borehole conditions.

It should be noted that the designed EL equipment has a higher resolution than LLS + LL + IL and is easier to operate, since it is configured as single device instead of three separate ones. The designed IL equipment has the same spatial resolution as IL probe, but enables to establish geoelectric parameters of reservoir bed without using other methods.

The lower spatial resolution of designed IL equipment as compared with EL hardware in the studied borehole is explained by specific resistivity of drilling fluid, at which the EL method gives more accurate results.

Hence, the objective to create a multi-probe equipment for high-resolution electric measurements of oil and gas wells has been successfully achieved.

However, it should be noted that current, rather low, prices for hydrocarbons (mainly, crude oil) and the economic crisis will not allow the Ukrainian geophysical corporations to essentially expand and to upgrade the hardware, which adversely affects the R&D works aiming at improvement of geophysical surveys of oil and gas wells.

In addition, it should be pointed out that while implementing R&D projects with direct involvement of commercial entities there are technical problems (prohibition against disclosure of information containing commercial secret which names of specific deposits or wells is referred to).

The research can proceed towards manufacturing other types of theoretically designed multi-probe oil and gas well electrometric devices [22–24] and carrying out their field tests under various borehole conditions.

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БАГАТОЗОНДОВА АПАРАТУРА ЕЛЕКТРОМЕТРІЇ НАФТОГАЗОВИХ СВЕРДЛОВИН

Вступ. Роботу присвячено створенню апаратури електрометрії, що здатна розв'язувати актуальні завдання геофізичного дослідження нафтогазових свердловин.

Проблематика. Існуюча в Україні апаратура не спроможна надійно вирішувати завдання геофізичного дослідження нафтогазових свердловин, зокрема й в умовах Дніпровсько-Донецької западини.

Мета. Створення та свердловинне випробування відповідної апаратури високої просторової роздільної здатності.

Матеріали й методи. Для створення багатозондової апаратури електричного каротажу використано можливість поєднання потенціал-зондів, що дозволяє встановлювати електричний потенціал вздовж осі свердловини і, відповідно, дозволяє розв'язувати обернену задачу з високою точністю. Для розробки багатозондової апаратури індукційного каротажу використано метод частотного сканування.

Результати. Розроблено два прототипи багатозондової апаратури та проведено свердловинні випробування їх габаритних макетів в умовах теригенного розрізу та порівняно її ефективність з вже існуючою в Україні апаратурою.

Висновки. Пропонована апаратура електричного каротажу має вищу роздільну здатність, ніж комплекс, що складається з апаратури бокового-каротажного зондування, бокового каротажу та індукційного однозондового каротажу, також вона є простішою в експлуатації, оскільки конструктивно є одним приладом, а не трьома різними. Розроблена апаратура індукційного каротажу, має таку ж саму вертикальну просторову роздільну здатність, як і існуюча однозондова апаратура індукційного каротажу, але натомість вона дозволяє встановлювати геоелектричні параметри пластів-колекторів без залучення інших методів дослідження.

Ключові слова: електрометрія, електричний каротаж, індукційний каротаж, нафтогазова свердловина.

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МНОГОЗОНДОВАЯ АППАРАТУРА ЭЛЕКТРОМЕТРИИ НЕФТЕГАЗОВЫХ СКВАЖИН

Введение. Работа посвящена созданию аппаратуры электрометрии, которая способна решать актуальные задачи геофизического исследования нефтегазовых скважин.

Проблематика. Существующая в Украине аппаратура не способна надежно решать задачи геофизического исследования нефтегазовых скважин в условиях Днепровско-Донецкой впадины.

Цель. Создание и скважинные испытания соответствующей аппаратуры высокого пространственного разрешения.

Материалы и методы. Используя возможность объединение потенциал-зондов, которая позволила восстанавливать электрический потенциал вдоль оси скважины и, соответственно, позволила решать обратную задачу с высоким пространственным разрешением, была создана многозондовая аппаратура электрического каротажа. Используя метод частотного сканирования создана многозондовая аппаратура индукционного каротажа.

Результаты. Выполнены скважинные испытания габаритных макетов разработанной аппаратуры в условиях терригенного разреза и проведено сравнение ее эффективности с уже существующей в Украине аппаратурой.

Выводы. Разработанная аппаратура электрического каротажа имеет более высокое пространственное разрешение, чем БКЗ + БК + АИК, также она более простая в эксплуатации, поскольку конструктивно представляет собой один прибор, а не три разных. Разработанная аппаратура индукционного каротажа, имеет такое же вертикальное пространственное разрешение, как и зонд АИК, но позволяет определять геоэлектрические параметры пластов-коллекторов без привлечения дополнительных методов исследования.

Ключевые слова: электрометрия, электрический каротаж, индукционный каротаж, нефтегазовая скважина.