SCA2003-57: EFFECTIVENESS OF A COMPLEX APPROACH TOWARDS THE STUDY OF THE WEST SIBERIA PUKURIAN SUITE RESERVOIRS PRESENTED BY POORLY CEMENTED ROCKS

(Fedortsov V., SRC “Sibcore”; Toporkov V., SCR “Tvergeophisica”;
Hairullin B., SPE “Sibburmash”)

This paper was prepared for presentation at the International Symposium of the Society of Core Analysts held in Pau, France, 21-24 September 2003

ABSTRACT
Only in the late 90-s a comprehensive solution for estimation of petrophysical parameters of the Pokurian suite poorly cemented reservoirs was suggested and realized in the Severo-Komsolskoye and Samotlor oil fields. The coring was run using the native-state core recovery method with placement of cores into the plastic inner core barrels and the core preparation for analysis was carried out by freezing it in liquid. The complex analysis of the cut core and core samples allowed to recognize a thin-laminated structure of the formation PK-1 in the field Severo-Komsomolskoye and to justify petrophysical relations for estimation of porosity, permeability and gas saturation of poorly cemented reservoirs.

INTRODUCTION
The problem of a correct estimation of the reservoir quality characteristics and saturation of the Pokurian suite formation PK-1 (Upper Cretaceous Senomanian deposits) in the oil field Severo-Komsomolskoye emerged as result of disagreement in the descriptions of the reservoir geological structure based on the field data. The geological structure was poorly studied first of all due to the fact that at the field exploration no good quality core was recovered except for one well drilled with oil-base drilling mud (OBM). The reasons of a poor core recovery and bad core material preservation were in the out-of-date methods of core collection applied in the 70-80s that were useless for collection of poorly cemented rock cores. To obtain reliable petrophysical data on the studied productive formation a decision was made to collect the core from PK-1 by the low-invasion method with using disposable plastic inner core barrels.

CORING PROCEDURE
The coring was run with the core barrel KIM manufactured in Russia with using the water-base polymer drilling mud as a circulation fluid. The penetration rate at a coring was high, up to 30 m/h in separate intervals. The core length did not exceed 3.5 m. In total about 28 m of core was recovered at 10 trips. To control the filtrate invasion the tracer fluorescein was added to the drilling mud. The laboratory studies [1] showed its concentration stability in time and absence of adsorption on the clay phase of water-base mud and in the rock. During coring in each 1.5-2 m of penetration the mud

filtrate samples were collected. The express analysis of the tracer concentration was run directly on the drill site. The fluorescein content in the filtrate was maintained at the level of 0.30-0.35 mg/dm^3.

The inner barrel with a core pulled out to the surface was placed horizontally on the platform with an extreme care. The barrel with a core was removed from the shield by hand and also very carefully. After placement of vertical marking the barrel was cut into one meter sections with a further preliminary preservation of the core faces. The face of one meter section was frozen in liquid nitrogen in a special chamber. The frozen piece of rock was removed from the plastic tube and a cylinder plug was cut out from the central portion of the piece for a direct determination of the preserved water saturation and electric resistivity. The plug was placed into the plastic covering and preserved. In parallel, a sample was collected to determine the concentration of the tracer in the pore space. The frequency of collection was 1 sample per meter of the core. After the sample collection was completed the core face sections were covered with wax and the tubes were packed into special boxes ensuring a rigid fixing.

LABORATORY STUDIES TECHNOLOGY

A direct determination of the preserved water saturation (S_{wp}) was made on the preserved core samples collected on the drill site. The determination of S_{wp} was performed by the extraction-distillation method in the retorts followed by additional extraction in Sohxlets. On each sample before placing it into the retort the electric resistivity (Rt) in surface conditions was measured. On all samples an ambient porosity was determined by Archimedes method as well as the density.

On the core in the plastic tube the gamma log was run. The natural gamma ray intensity curves obtained on the core permitted to make more exactly the core tying to the radioactivity logging curves. Then the core in the tubes was frozen in liquid nitrogen and cut lengthwise in ratio 1:3. Drilling out of plugs was made from the longitudinally cut frozen core also with using liquid nitrogen. The plugs were placed into the Teflon casing to prevent their destruction in the process of further study and then were analyzed similarly to the normally cemented cores. On the plugs in the covering the rock porosity, permeability and density were measured by conventional methods. Using special petrophysical analyses the permeability for reservoir fluid and effective permeability for gas were investigated both in the ambient conditions and in the simulated reservoir conditions. At effective pressure the velocities of the elastic wave propagation were determined as well as the cementation exponent "m" was estimated. On the set of the core samples the study of capillary characteristics was run using the porous plate method. The longitudinal sections of the core were photographed in white and UV light. After photographing some samples were collected to study the mineralogy on thin sections, the rock particle size distribution using the laser microanalyzer, the composition of the cement clay minerals using the X-Ray analysis, the composition of carbonate minerals using the thermogravimetric method. The pore space morphology and structure were studied by scanning electronic microscopy.

Basing on the performed analyses results the geologist made a detailed description of the studied formation and a lithological-and-physical section was prepared.

THE STUDIES RESULTS

The reservoir geological structure

In the investigated Severo-Komsomolskoye field well the formation PK-1 occurs in the depth interval 1100-1800 m and has a complicated structure: the upper part of the formation in the interval 1101-1111 m (gas saturated), the middle part in the interval 1111 – 1120 m (oil saturated) and then the lower part (water bearing). The oil viscosity is more than 5 cP in reservoir conditions. The reservoir is presented by a non-uniform alternation of sand-clay-siltstone rocks. The pictures of the longitudinally cut core give a visual proof of the laminated structure of the formation in its productive portion. The thickness of the clay and sand-siltstone interlayers varies from the first mm in the intervals of the thinly laminated interbedding up to 15-25 cm in the intervals of the alteration. The laminated character of the reservoir defined on the core has changed dramatically the knowledge about the geological structure of the formation PK-1 (earlier the geologists suggested the reservoir as homogeneous).

Estimation of porosity and permeability

In the best reservoirs the porosity in the surface conditions exceeds 40% and permeability for gas reaches 1000mD and more. The permeability estimation in the reservoir conditions showed a significant reduction in the magnitudes of the parameter as related to the measurements in the ambient conditions. The reduction in porosity at transition from the surface to the in-situ conditions for the worst reservoirs (30%) makes up 3.5% of absolute values and for the best reservoirs (40%) – 2.5% (Fig.1). These data agree well with our results obtained for poorly cemented Senomanian reservoirs in the field Samotlor [1, 2].

To estimate the quality of the reservoir in permeability the latter was determined in various conditions. Initially, there were determined the permeabilities for helium and formation water in ambient conditions, and on samples after capillarimetery the effective permeability for helium was measured. In reservoir conditions (at effective pressure) the permeability for formation water and the effective permeability for helium were determined. The results obtained are presented in Fig. 2-4.

It is not correct to use the values of permeability for gas received on a dry sample (Fig. 2) for estimation of a reservoir quality of a similar type as well as to use the values of permeability for reservoir water. In the first case the actual permeability value is significantly overestimated and in the second case it is underestimated.

The effective permeability for gas reflects most closely in-situ permeability in the zone of ultimate oil saturation. A close position of the regression lines approximating the correlations for both, the in-situ and the surface conditions (Fig. 4), suggests a proportional influence of pressure and temperature and makes it possible to use the results obtained in the ambient conditions for estimation of a real permeability of a reservoir.

Estimation of oil saturation

For each core sample collected for analysis of S_{wp} the fluorescein concentration in the pore space and a total mineral composition of the pore water were determined. The complex analysis of the polymer drilling mud filtrate invasion in the pore space of the core revealed that the dilution did not exceed 10%. Only in two samples the invasion was more than 12,4 and 10,1%, respectively. For the remaining samples the invasion was 9% (as a rule, 5-6%). Thus, from the sampling only two samples were excluded.

The received results of S_{wp} were recalculated to bulk water saturation (S_{bw}). S_{bw} and Rt estimated on low invasion core were compared with the earlier OBM core studies results from another well. The agreement of the results obtained on low invasion cores and on OBM cores, shown in Fig. 5-6, is very close. A good agreement with the direct methods data is also demonstrated by the "irreducible" water saturation, measured on porous plates (Fig. 5).

To estimate oil and gas saturation (S_{og}) by LOG data we used the equations

$$\log Rt = 3.06 – 1.89 * \log S_{bw} \quad \textbf{(a)} \text{ for the low invasion core}$$

$$\log Rt = 4.13 - 3.5 * \log S_{bw} + 0.53 * \log S_{bw}^2 \quad \textbf{(b)} \text{ for the OBM core.}$$

To estimate S_{og} by a conventional method basing on the porous plates data we constructed the plots of relationships and received the next equation:

$$\log F = 3.43 – 1.70 * \log ? \quad \textbf{(c)}$$

$$\log I_R = 3.22 – 1.62 * \log S_w \quad \textbf{(d)}$$

where **F** – Formation Factor, ***?*** – Porosity, $\mathbf{I_R}$ – Resistivity Index, $\mathbf{S_w}$ - water saturation. The values of the cementation exponent "m"=1.70 and saturation exponent "n"=1.62 agree well with the results received earlier by other scientists [3, 4, 5].

In the intervals of low invasion coring the S_{og} estimation was made basing on data received by electrical logging methods. The S_{og} values obtained by different methods are given in Table 1.

Table 1. Results of S_{og} calculation

N/N	Interlayer thickness, m	Saturation type	f, % core,	f, % LOG	S_{og}, % Low-invasion core,	S_{og}, % Eq.a	S_{og}, % Eq.b	S_{og}, % Eq.c+d
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	2.0	Gas	33.7	30.7	49.6	45.2	43.8	35.5
2	2.1	Gas	35.5	38.2				
3	2.1	Gas	31.8	32.1	46.2	53.9	52.1	49.5
4	3.3	Gas	35.3	37.8	55.0	67.7	55.3	64.0
5	1.4	Oil	30.6	33.2	47.0	56.9	52.9	46.6
6	4.5	Oil	32.1	30.2	61.3	47.3	49.7	45.1

Note: column 6 - by low invasion core
column 7 – by logging (based on equation **a** for low invasion core)
column 8 - by logging (based on equation **b** for the OBM core)
column 9 – by logging (based on equation **c+d** for porous plate data)

CONCLUSION

A use of the low invasion coring technology in sections presented by poorly cemented reservoirs saturated with high viscosity oils and the low temperature core preparation determined the potentials of the full-value study of poorly cemented core. As a result of the performed studies the following was achieved:

- The new specific features have been revealed of the lithology and facial conditions of the producing formation PK-1 generation.
- The rock lithology effect on the reservoir quality characteristics has been studied. A procedure has been offered for estimation of the reservoir quality for the Pokurian suite poorly cemented rocks.
- A low degree of the oil-base mud filtrate invasion into the core has been proved and an initial oil and gas saturation in the low-invasion core has been evaluated.
- A practical feasibility has been shown of the formation parameters estimation by logging data on the basis of the obtained core data.

REFERENCES

1. Artemova I.S., Fedortsov V.V., et. al. “Laboratory method of quantitative estimation of drilling mud penetration at low invasion coring”. Proceedings of 13-th Scientific and Practical Conference of Junior Scientists and Specialists from OJSC “SibNIINP”, Tyumen, 2002, p.217-223.
2. Hairullin B.Y., V.V. Fedortsov V.V., et. al., “The specific features of coring and study of cores from the high viscosity oil reservoirs in the West Siberia Pukurian Suite”, Transactions of the 3rd International Scientific and Practical Conference “Development of Difficult-to-Recover High Viscosity Oils”, Kasnodar, 2001.
3. Rudakovskaya S.Yu. “Development of Technology for Petrophysical Support of Interpretation of Logging Carried Out in the Sections Presented by Poorly Cemented and Unconsolidated Deposits”. Thesis for the Candidate of Science Degree Competition, Tver, 1999.
4. Argau M., “Capillary Pressure and Resistivity Index Measurements on Unconsolidated Sands from Frigg Gas Field”. 11th European Formation Evolution Symposium Transactions, Norwegian Chapter, Society of Professional Well Log Analysts, 1988.
5. Svanson B.F., Thomas E.C., “The measurements of Petrophysical Properties of Unconsolidated Sand Cores”, paper A in the 6th European Formation Evaluation Symposium Transactions: Society of Professional Well Log Analysts, 1980.

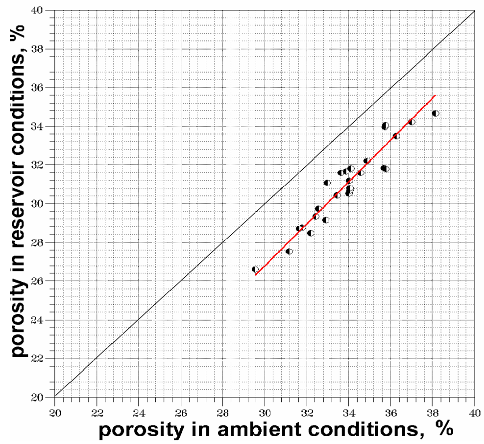

Fig.1. Porosity in reservoir and in ambient conditions.

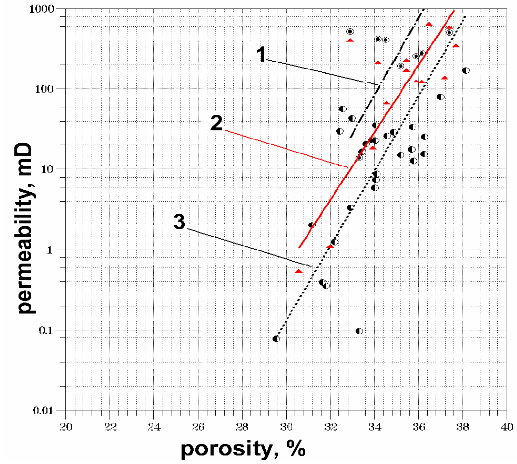

Fig.2. Permeability vs porosity in ambient conditions: **field 1**-gas permeability;
field 2–effective gas permeability;
field 3–water permeability

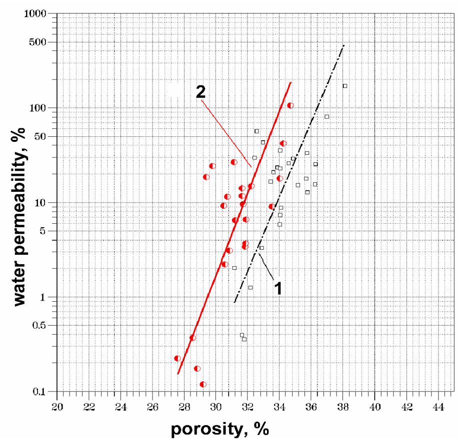

Fig.3. Water permeability vs porosity.
Overbern pressure: **1**- 1.4 MPa; **2**- 11.5 Mpa

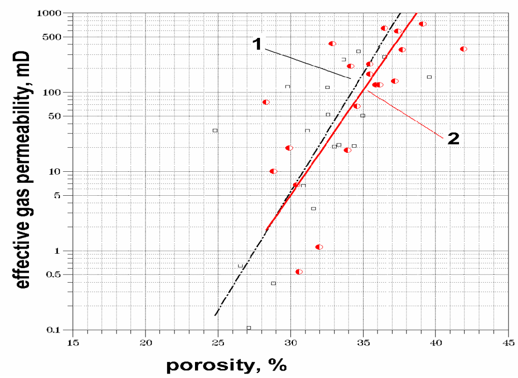

Fig.4. Effective gas permeability vs porosity.
Overbern pressure: **1**- 1.4 MPa; **2**- 11.5 Mpa.

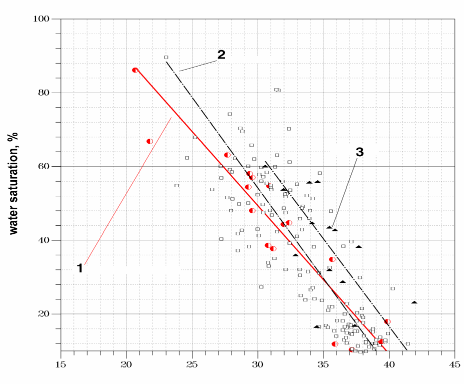

Fig.5. S_w–porosity comparison.
field 1-low invasion core;
field 2–OBM core;
field 3-S_{iw} by porous plate.

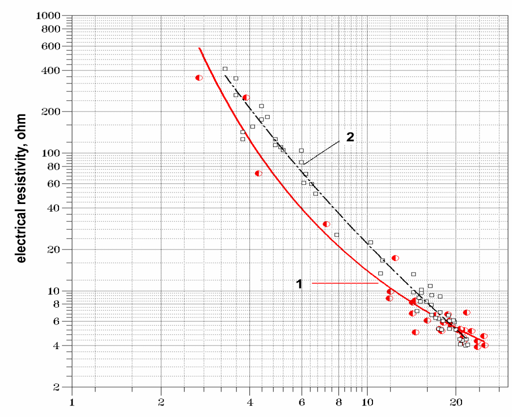

Fig.6. Rt–S_{bw} core comparison.
field 1-low invasion core;
field 2–OBM core.