

Scope of Work
For Salman-2 Well Core Analysis

1. Work objectives

1.1. The Contractor shall undertake laboratory studies of the rock samples obtained from Salman-2 well.

2. Work target and scope of Work

2.1. The studies are targeted at the rock core samples obtained from Salman-2 well.

3. Key Work requirements

3.1. The core materials shall be delivered to the laboratory by the Contractor at own cost against a Delivery and Acceptance Certificate no later than within thirty (30) calendar days after the cores were collected.

3.2. The Customer shall, in a timely manner and subject to the Contractor's request, provide all available geological and geophysical information necessary for a quality Work performance by the Contractor.

3.3. The Work shall be performed in the scope stipulated in the Study Program (Annex 2) and within the time frame set forth therein, provided that no technical problems or otherwise occur, which may prevent from quality and timely performance of the Work in the approved scope. In the event that the Work performance fails to meet the time limits or the full scope of the Work, the Contractor shall, in sufficient time in advance, agree with the Customer on time and scope rescheduling or change.

3.4. Laboratory core study procedures are described in Annex 1.

3.5. The Contractor, upon the Customer's request, shall within three (3) business days provide to the Customer the operational data on core studies.

3.6. To ensure the study quality control, the Contractor shall provide access to the Customer's representative upon a relevant request by the Customer.

4. Geological tasks and solving methods

4.1. The deliverables of the integrated studies of the rock samples obtained from the Customer's wells are necessary to perform reserve calculation and design development plans.

5. Scope of Work

5.1. The scope and duration of the Work are subject to adjustment based on actual receipt of the core materials.

6. Expected deliverables and reporting

6.1. Upon completion of the studies of the core material obtained from each well, the Contractor shall submit to the Customer a core study report.

6.2. The operational analysis results received shall be provided to the Customer on an on-going basis in electronic form.

6.3. The Work Results Report shall be provided in two hard copies and in electronic form on digital media (CD) in two copies.

7. Work completion schedule

7.1. The laboratory core studies shall be carried out in accordance with the Technical Assignment and Work Program.

7.2. The time limit for the performance of any additional Work unstipulated by a standard core analysis package shall be determined upon a mutual agreement of the Parties.

Laboratory core study procedures

1. Technological measures during core handling at surface

1.1. Removal of the core recovery tube from the core sampling assembly

During core sampling with the use of core barrels where the cores are located inside the tube (a double-tube, isolated technology), tube recovery from the core barrel tube shall be performed with the use of a hoisting winch at the drilling site with no tube impact with the equipment and rig floor allowed. In the event that the tube is of great length, the tube shall be dismantled at the drilling site with the use of a special core cutter.

1.2. Спуск керноприёмного тубуса на мостки Landing the core recovery tube on the ramp

During core sampling with the use of core barrels with inner tubes made of fiber-glass plastic or any other insufficiently stiff material, landing the tubes from the rotary table on the V-door ramp shall be performed with a mandatory fixation of the core containing tube with the use of a device preventing any tube flexure, “a racking skid”. During landing, an outer steel barrel may be used as a “racking skid”.

The optimal designs of the “racking skids” are those allowing a remote fixation of the inner core tube with joint tools, in which case no rig personnel is required to be lifted to the upper part of the skid.

To avoid flexures causing core damage, it is important that the cores are placed vertically only until they are fixed in the racking skid. Further, the racking skid shall be pulled down on the loading platform.

Pulling down fiber-glass plastic tubes containing hard-to-recover reserve cores without any latching mechanisms is prohibited.

When marking an inner core tube, waterproof markers shall be used; it is recommended to have pre-prepared sets of auxiliary tools available for a quality marking of inner core tube.

After placing on the V-ramp, the tube shall be washed clean of the drilling mud residues and rubbed dry.

It is recommended to use a tube with a factory double-line marking with an indication of the direction of the core entry point to the tube. In the absence of marking, the inner core tube shall be double-line marked with two contrast colors along the entire length.

Measure out the distance from the inner core tube top to the core roof in the tube. In case of a 100% core recovery this distance shall make about 40 cm (a length of the core column in the core cutter shoe). Mark the position of the core roof on the inner core tube. This mark will be the top of the first tube.

Carefully move the cores from the core cutter assembly into the pre-cut empty pipe section of a

corresponding length maintaining core orientation in relation to the tube marking. “Pushing” cores from the core cutter assembly into the inner core tube is prohibited.

Mark out the inner core tube by one-meter sections (or by any other length in accordance with the Geological and Technical Assignment) starting from the core roof mark.

Each one-meter section shall be marked in numerical order (in “1 of 9”, “2 of 9”, etc. format) with “Top” and “Bottom” indications and with the indication of roof and bottom depths; field name, well number and coring interval data shall be marked on the tube section as well.

1.3. Cross-sectional cutting of cores (segmentation)

Cross-sectional cutting of tubes shall be performed in accordance with the marking. Cross-sectional cutting of the tube containing consolidated cores shall be performed with special tools (angle grinders, etc.). When cutting a tube containing non-consolidated or poorly consolidated cores, the possibility of core damage shall be entirely precluded: preclude pipe flexure, rotation, shock, drop and etc. To this effect, the cross-section cutting shall be performed with a diamond blade of a large diameter, more than twice as large as the inner core tube diameter, and in a single run, provided that the inner core tube is securely fixed with the use of a special tool.

For non-consolidated and poorly consolidated cores, it shall be prohibited to:

- Recover cores from the inner core tubes;
- Cut the inner core tube with hand tools (angle grinder, etc.) to its partial depth with tube rotation.

During cross-sectional cutting, the following operations shall be performed at each cut:

- Photograph the cut core face. To solve special problems (assessment of drilling mud filtrate invasion, etc.), the photograph shall be also taken in UV-light.
- Make a brief lithological description of the cut core face.
- When it is required to collect a moderate amount of core samples for instant core analysis, the samples shall be placed in hermetically sealed plastic bags with the indication of the sampling depth. All collected core samples shall be photographically documented with the indication of linear dimensions (a photograph with a rule).
- Set a rubber closing cover of a matching diameter; ensure that the cover is hermetically pulled up to the tube with a metal collar.

1.4. Boxing of cores, marking of boxes

The prepared tubes with cores inside shall be placed in special lid boxes. The box shall contain meshes for three-meter tubes with cores, unless the Geological and Technical Assignment states otherwise. The tubes shall advance in the box without restraint. To minimize damage of cores during transportation after box packaging the tubes shall be fixed in the boxes with the use of foam insulation (apply to at least two zones of 5-10 cm in length from each tube side).

Core box packaging shall be performed in the order of increasing depths starting from the top left box

angle and down to bottom right angle. The direction of the depth increase of the collected cores during box packaging shall be always maintained from left to right.

After the core was packaged, the box shall be marked. The marker shall be waterproof. Further, the face and side box surfaces shall bear the following information: the sequence number of the box, field data, well number, interval of core sampling of the cores packaged in the box (interval roof and bottom, core recovery).

On the lateral side of the box the field name, well number, coring interval and box number shall be indicated with indelible ink.

After core packaging and box tagging the box shall be covered with a lid, and the lid shall be secured either with nails or with the use of special locks. To maintain the box strength, the end face of the box shall be edged with a metal strip. The boxes may contain either one or more sections. The number of sections shall be determined based on the diameter of the sampled cores. For 130-mm diameter cores single-section boxes are recommended; for 110-mm diameter cores two-section boxes, for 100-mm diameter cores three-section boxes, for 80-mm diameter cores four-section boxes, and for 67-mm diameter cores five-section boxes shall be used.

Aside from wooden boxes, plastic boxes of various designs may be used for core transportation.

2. Core treatment (in laboratory conditions)

2.1. Receipt and photography of the boxes containing core materials

Upon arrival from the drilling site of the boxes with core materials, the following operations shall be performed:

- Compare the amount of cores with the data provided in the core sampling report (against an Acceptance and Delivery Certificate) and make sure that the cores did not get lost during transportation. Indicate all core damages and deformations caused during core handling at the well and in the course of transportation;
- Check the numbering and order of the transportation containers (boxes) to ensure conformance with the cumulative depth;
- Check for the tube marking;
- Evaluate tubes' pressure integrity;
- Photograph the core materials in containers;
- Draw up an Acceptance and Delivery Certificate in duplicate, a copy whereof shall be furnished to the Customer.

2.2. Core Gamma-ray spectral log

- Prepare the Gamma-ray spectral logging unit to take measurements in accordance with the instruction manual (calibration is mandatory);
- Carefully place the tube on the tool travelling belt;

- Align the tube start (top) with the unit zero mark;
- Measure profile Gamma-ray spectral log;
- If required, make depth adjustments of the obtained results in order to preclude any errors resulting from the presence of transport plugs on the tubes (which leads to a fictional extension of the core column).

2.3. Density log

- Prepare the density logging unit to take measurements in accordance with the instruction manual (calibration is mandatory);
- Carefully place the tube on the tool travelling belt;
- Align the tube start (top) with the unit zero mark;
- Measure profile density log;
- If required, make depth adjustments of the obtained results in order to preclude any errors resulting from the presence of transport plugs on the tubes (which leads to fictional extension of the core column).

2.4. X-ray tomography of a full-size core with tomogram interpretation

- Prepare the X-ray tomograph to take measurements in accordance with the instruction manual
- Carefully place the tube on a specialized table (either horizontal or vertical);
- Acquire a tomogram;
- Assess the tomogram quality;
- If the quality is good, proceed to the next tube survey;
- Upon completion of the acquisition, carry out interpretation of the obtained tomograms supported with the report containing the following data: determination of X-ray density along the core, qualitative and quantitative fracture assessment, stratification information, 2D tomograms for each tube along the core axis and perpendicular to it.

2.5. Photography of cores in daylight and UV-light

The cores shall be photographed with a specialized device in colorless light and UV-light with the use of a high-resolution digital camera fixed on a special stand. The camera shall be connected with a PC, wherefrom the photography process is controlled. To lay out full-size cores special one meter long trays are used, and the cores are laid out in accordance with the spudding and recovery data within each sampling interval. Typically, the cores are photographed in natural light (5,500 K) and in UV-light (254-365 nm). In UV-light the photographs are taken with the use of BLB-lamps equipped with an inline narrow-band “stimulating” light filter in order to extract an optimal emission spectrum and reduce visual light transmission. A UV-barrier filter fixed up to the camera lens blocks the UV-emission and transmits to the light-sensitive camera matrix only a visible portion of the spectrum.

2.6. Core slabbing

Slabbing of full-size cores in the ratio of 1:3 shall be performed with the use of specialized equipment with either rotary or band saw. The minor part of the core (1/3) is called the “end piece” and is intended for a long-term storage. The larger part of the core (2/3) is typically used for making samples. During slabbing, it is necessary to consider the angle of inclination along stratification; control over the penetration angle shall be mandatorily conducted with the use of the directional survey data. On the face side of the core the maximum angle of inclination shall be displayed.

2.7. Photography of a core column in daylight and UV-light

Photography of the core column after slabbing shall be performed with a specialized device in colorless light and UV-light with the use of a high-resolution digital camera fixed on a special stand. The camera shall be connected with a PC, wherefrom the photography process is controlled. For laying out full-size cores special one meter long trays are used, and the cores are laid out in accordance with the spudding and recovery data within each sampling interval. Typically, the cores are photographed in natural light (5,500 K) and in UV-light (254-365 nm). In UV-light the photographs are taken with the use of BLB-lamps equipped with an inline narrow-band “stimulating” light filter in order to extract an optimal emission spectrum and reduce visual light transmission. A UV-barrier filter fixed up to the camera lens blocks the UV-emission and transmits to the light-sensitive camera matrix only a visible portion of the spectrum.

2.8. Determination of lateral permeability of core materials

Lateral permeability may be measured with the use of automated scanning permeameters with combined gauges (of AvtoScan II type) or with the use of equipment, which allows registering one parameter only.

The slabbed core shall be placed on a robotized platform. The platform automatically positions the probe permeameter on an embedded XY table. The table control is provided with the use of the equipment software and built-in digital motion controllers, which provide for the positioning accuracy of 0.1 mm. The probe permeameter consists of a measuring probe, which is pressed under pressure to the rock core surface and through the probe aperture pressurized nitrogen enters the sample.

During filtration, the gas passes through the rock and comes out into the atmosphere. Gas flow lines develop a semi-spherical shape. The probe tip seal made of soft rubber prevents gas leaking in the zone of the probe’s contact with the core surface. Mass-scale measurements are performed within the interval of 5-10 cm.

2.9. Determination of acoustic wave velocity

Acoustic logging (compressional and shear wave velocities) may be measured with the use of automated scanning permeameters with combined gauges (of AvtoScan II type) or with the

equipment, which allows registering one parameter only. Measurements of core acoustic properties shall be performed on the equipment fitted with acoustic signal transmitters and receivers.

3. Core preparation

3.1. Making standard-size thin sections (1 thin section per 1 lin m of core)

3.2. Making core plugs (30 mm in diameter) (3 plugs per 1 lin m of core)

To produce samples of a regular geometric shape, hard-alloy or diamond bits and diamond wheels shall be used. After the sample is produced, a laboratory number shall be put on the sample.

3.3. Extraction of core plugs (30 mm in diameter)

The pore volume of core samples shall be cleared of the initial fluids by way of washing-out or contact treatment with the use of various solvents aimed at HC, water and drilling mud extraction. There are a large number of core sample extraction methods. The most widely used extraction method is Soxhlet extraction, being the most widespread and universal.

In CO₂ extractors, core clearing is performed by way of alternate injection of solvents and CO₂ into the core samples, which method is not recommended for either clearing the cores damageable when in contact with formation fluid and CO₂ mix or for clearing of non-consolidated, poorly consolidated or oil-source rocks.

In centrifugal extractors centrifugal force is used to wash core samples, which results in the replacement of oil (and water). It is not recommended to use centrifugal extractors for a mass-scale core sample clearing as they show reduced extraction efficiency in comparison with Soxhlet extractors (Colin McPhee).

During clearing with the use of flow extractors by way of solvent circulation the core samples are placed in individual sample holders. This cleaning method is rather labor consuming and is applied only during preparation of core samples for special petrophysical or filtration surveys.

Chloroform, carbon tetrachloride, benzene, toluene, kerosene, spirit and blends thereof are used as solvents. The most widely used solvent is spirit and benzene mixture in the ratio of 1:3; other solvent combinations are acceptable as well.

3.4. Washing off salts from core plugs and core drying

After extraction the samples shall be placed into the ventilation hood for weathering. The weathering period takes about 24 hours.

After that the samples are washed free from salts in main water.

Further, the samples enter the drying zone. Sample drying shall last till the mass of the samples becomes constant. Sample drying time may seriously vary; nevertheless, the drying period usually lasts at least four hours.

4. Standard core analysis

4.1. Determination of Klinkenberg-corrected absolute permeability to gas, effective porosity and

matrix density by gas volumetric method

Determination of porosity by gas volumetric method shall be performed with the use of the equipment listed below:

- AP-608 by CORETEST SYSTEMS INC;
- UltraPoroPerm-500 by CORE LABORATORIES INSTRUMENTS;
- UltraPore™-300 by «CORE LABORATORIES INSTRUMENTS»;
- DHP-200 by WEATHERFORD LABORATORIES;
- PIK-PP by Geologica;
- other analogue equipment.

Measurements shall be performed in accordance with the equipment user manual. Calculations shall be performed on the software provided by equipment manufacturers. To perform calculations, procedure instructions have been developed for each software product.

When using UltraPore™300 and DHP-200 helium porosimeters or similar, the sample shall be placed in a sealed metal calibrated container. When both the container and the sample are filled with helium, the sample solid volume (V_{solid}) is measured.

The open porosity numeric value shall be determined as the ratio of inter-related pores volume in the sample (V_{II}) to the bulk rock volume ($V_{\text{обп}}$):

$$K_{\text{II}} = \frac{V_{\text{II}}}{V_{\text{обп}}}$$

Bulk rock volume shall be calculated by the core sample dimensional size, provided that it represents a geometrically regular cylinder.

Pore volume is calculated as a difference between the bulk sample volume and sample solid volume:

$$V_{\text{II}} = V_{\text{обп}} - V_{\text{TB}}$$

This determination is based on Boyle-Mariotte's law for calculation of sample solid volume by helium target weight expansion in a calibrated mesh.

Boyle-Mariotte's law:

$$(P_1 \cdot V_1) = (P_2 \cdot V_2)$$

where:

P_1 – initial pressure, MPa;

V_1 – initial volume, cm^3 ;

P_2 – final pressure, MPa;

V_2 – final volume, cm^3 .

The equation used to calculate the solid volume is derived from the fundamental Boyle-Mariottes' law as follows:

$$(P_1 \cdot V_K) = P_2 \cdot (V_K + V_{TB})$$

$$V_{TB} = \frac{P_1 - P_2}{P_2} \cdot V_K$$

$$V_K = V_{K1} + V_{K2}$$

where:

V_{K1} , V_{K2} – containers of a calibrated volume included in the instrument measuring circuit.

With the use of calibration in relation to the known reference volume, a relationship between the grain volume and $\frac{P_1 - P_2}{P_2}$ ratio may be determined.

When measuring open porosity with UltraPoroPerm-500 and AP-608 gauges or similar, a sample in a rubber collar is placed into a hydrostatic core holder and undergoes a hydrostatic compression similar to the one used when determining permeability to gas.

Porosity shall be determined by a volumetric method by way of filling the sample with gas (helium) from the calibrated volume.

UltraPoroPerm-500 and AP-608 units and analogues apply the Boyle-Mariotte's law (10) for calculation of sample solid volume by helium target weight expansion in a calibrated mesh.

The equation used to calculate the pore volume is derived from the fundamental Boyle-Mariottes' law as follows:

$$P_1 \cdot V_K = P_2 \cdot (V_{\text{паразитн}} + V_{\Pi})$$

$$V_{\Pi} = \frac{P_1}{P_2} \cdot V_K - V_{\text{паразитн}}$$

где:

V_K – the volume of the calibrated mesh included in the instrument measuring circuit;

$V_{\text{паразитн}}$ – the volume of delivery tubes to be considered in the process of instrument calibration.

4.2. Determination of effective porosity to water, bulk and matrix density by calculation

The subject matter of determination of rock sample porosity by way of saturation is to determine the void volume and external sample volume by the results of air and saturating liquid weighing of a dry and saturated sample. The sample void volume shall be determined by the difference between dry and liquid saturated sample masses. The external sample volume shall be determined by the difference between the masses of the liquid saturated sample in air and in saturating liquid. Open porosity shall

be determined by division of the first volume by the second volume.

To determine open porosity the samples shall be dried in the drying oven at $105 \pm 2^{\circ}\text{C}$ maintaining control over the sample mass change accurate to ± 0.001 g. When a constant sample mass is reached, the drying shall be stopped. Clay samples shall be dried at $70 \pm 2^{\circ}\text{C}$ maximum.

Before weighing the samples shall be cooled down in the desiccator above ignited silica gel.

Sample weighing shall be performed prior to model operating fluid saturation. The weighing accuracy shall be maintained at ± 0.001 g minimum. Dry sample weighing results shall be registered in the laboratory log.

Sample saturation with the operating fluid shall be performed as described below.

Dry weighed samples shall be placed into a crystallizing tank, which shall then be placed into a vacuum sample saturation unit reservoir. The container is then filled with the operating liquid and a separate vacuum treatment is separately performed for the samples and saturating liquid.

Liquid vacuum treatment shall run on till vigorous evolution of gas bubbles stops. Dry sample vacuum treatment duration shall be determined in accordance with the recommended mode (Table 1).

Table 1

Recommended modes of rock sample saturation

Sample mass, g	Permeability, mkm^2	Duration, hrs			
		Sample vacuum treatment	Vacuum capillary imbibition	Up to saturation	
				Under atmospheric pressure	Under pressure
From 20 to 60	10^{-2}	2	0.2	10	0.5
	$10^{-3} - 10^{-2}$	3	0.5	24	1.0
	$10^{-4} - 10^{-3}$	4	0.5	48	1.5
	10^{-4}	6	1.0	72	2.0
From 300 to 800	10^{-2}	3	0.5	24 – 48	1.0
	$10^{-3} - 10^{-2}$	4	1.0	48 – 72	2.0
	$10^{-4} - 10^{-3}$	5	2.0	72 – 96	3.0
	10^{-4}	8	2.0	96 -192	4.0

Upon the expiry of sample vacuum treatment time, a small amount of liquid shall be fed in such a way that the liquid layer covers the bottom of crystallizing tank to the height of 1 cm to create capillary imbibition conditions. Then the level of liquid in the crystallizing tank is lifted stage by stage to the height of at least 1 cm beyond the samples, and vacuum treatment is performed till vigorous evolution

of gas bubbles stops. The pump then gets shut down, the pressure equalization valve gets slowly open and the crystallizing tank with samples is removed.

The samples are then placed in the saturator and further saturated with the operating liquid creating an excess pressure in the saturator camera of 5-15 MPa. Such further saturation takes 2-4 hours. During such further saturation and subsequent operations the samples shall be soaked under the liquid level to prevent any contact with the atmosphere.

After saturation and further saturation the samples shall be hydrostatically weighed, thus determining the mass of the submerged sample. The saturated samples shall be weighed to the accuracy of ± 0.001 g. To this purpose the liquid that was vacuum treated during vacuum sample saturation shall be used. The sample shall be placed on a lifting bar and dipped into the liquid entirely. The sample shall not touch any bowl walls and bottom, and the level of liquid in the bowl in the equilibrium moment shall be levelled at the same mark for all samples in the party.

The mass of the lifting bar shall be deducted from the readings of the electronic weighing machine during calibration.

The sample shall then be placed back into the crystallizing tank under the liquid level. Upon hydrostatic weighing of the sample party these samples shall be weighed in air.

The sample shall be removed from the crystallizing tank, and excess liquid shall be removed from its surface with filter paper moistened with the same liquid. Then the mass of the saturated sample shall be determined.

Open porosity factor (Кп) in percentage terms shall be calculated according to the formula below:

$$Kn = \frac{M_3 - M_1}{M_3 - M_2} \cdot 100 \%$$

where:

M_1 - the mass of a dry rock sample;

M_2 - the mass of a liquid saturated rock sample in saturating liquid;

M_3 - the mass of a liquid saturated rock sample in air.

The volume density of rocks containing no isolated void channels shall be derived from sample testing results when determining open porosity in accordance with the formula below:

$$\gamma_0 = \frac{M_1 * \gamma_{\text{жс}}}{M_3 - M_2}$$

where:

γ_0 - the volume density of the rock sample, g/cm³;

$\gamma_{\text{жс}}$ - operating liquid density, g/cm³.

The apparent matrix density ($\delta_{\text{м.п.}}$) of the channels containing no isolated voids shall be derived from sample testing results when determining open porosity in accordance with the following formula:

$$\delta_{\text{м.п.}} = \frac{M_1 \cdot \delta_{\text{жс}}}{M_1 - M_2},$$

where:

$\delta_{\text{жс}}$ - operating liquid density.

4.3. Determination of true resistivity in 100% water saturation under weathering conditions to develop a porosity parameter/porosity tie

When measuring true resistivity, the following operations shall be performed:

Preliminarily, contact resistance between electrodes and the sample shall be determined. To this effect, the electrodes with cushions and without samples shall be pressed to each other with a force of 0.3 MPa, which shall be controlled with a pressure gauge.

When excess water is removed with wet filter paper from the surface of the saturated sample, the mass of the completely saturated sample (m_1) shall be weighed in air. Right afterwards the tested sample shall be placed into the core holder between the electrodes with cushions of two layers of filter paper with a mechanical pressing of 0.3 MPa. At the same time the instrument display shows the value of overall resistance of the sample and electrodes with cushions ($R_{\text{н}}$).

The resistivity of a model formation water solution ($\rho_{\text{в}}$) shall be calculated in accordance with the formula below:

$$\rho_{\text{в}} = A \cdot R_{\text{р-па}},$$

where:

A – measuring cell coefficient, m.

Value A shall be determined preliminarily on solutions with a known resistance value.

$R_{\text{р-па}}$ – a measured resistance value of the model formation water solution, Ohm.

5. Lithological and sedimentological analysis
 - 5.1. Layer-by-layer core description after slabbing
 - 5.2. Standard thin section petrographical analysis (description)
 - 5.3. Determination of carbonate content and undissolved residue content (CHO)
 - 5.4. Grain composition
 - 5.5. Preparation of core samples for X-ray diffraction analysis
 - 5.6. X-ray diffraction analysis
 - 5.7. Preparation of samples for X-ray diffraction analysis of clay fraction (terr.)
 - 5.8. Preparation of samples for X-ray diffraction analysis of clay fraction (carb.)
 - 5.9. X-ray diffraction analysis of clay fraction composition

- 5.10. X-ray fluorescence rock analysis including sample making
- 5.11. Studies of pore volume morphological features and structure by scanning electron microscopy method
- 5.12. Biostratigraphic studies (including issuance of the rock age statement)
- 6. Special core analysis
- 6.1. Obtaining of a capillary pressure curve including determination of residual water saturation (by porous plate method or centrifuging) (at least 8 points)

The laboratory method of determination of the water saturation factor of the pore volume in capillarimeter is based on mobile formation fluid drainage from a rock sample through a porous plate under excess gas pressure of a known value in the capillarimeter camera. The rock sample is exposed to the pressure of a known value within a pre-determined period of time required to stabilize the sample's water saturation. Upon the cycle completion, the change of the sample mass shall be registered, and the process shall be repeated at a higher pressure level.

Prior to placement of 100% of saturated samples on the plate these shall be weighed on a high-accuracy weighing machine, and the measurement results shall be registered in the laboratory log to the accuracy of $\pm 0,001$ g.

For a more robust capillary contact between the porous plate and the samples, a thin filter paper interlayer saturated with model formation water shall be evenly laid down on the plate. The samples shall be carefully placed on the interlayer with pincers. Metal meshy-bottom weights shall be put on tops of the samples.

Close the camera lids and screw up the clamp tightly.

Set the values of gas pressure in accordance with the experiment plan.

The end of the test at the given pressure value shall be determined when the water stops flowing out of the camera.

Open the camera lid, remove and weigh the samples; the weighing results shall be registered in the laboratory log to the accuracy of $\pm 0,001$ g.

After weighing the samples shall be placed on the plate again. Repeat the testing procedure under the next pressure value.

Based on the results of the sample mass measurement, sample water saturation factor at each pressure value shall be calculated in accordance with the formula below:

$$K_{ei} = \frac{M_i - M_C}{M_B - M_C} \times 100\% ,$$

where:

K_{ei} - sample water saturation factor under capillary pressure P_{ki} , %;

M_B - sample mass with 100% saturation, g;

M_i - sample mass under operating pressure in the camera P_{ki} .

Based on the data obtained, a dependency diagram for rock sample water saturation factor (КВ) and capillary pressure P_{ki} shall be built.

The laboratory method for the determination of the pore volume water saturation factor by way of centrifuging is based on mobile formation fluid drainage from the rock sample under the pressure arising during sample rotation in the centrifuge bowl with a preset constant speed during a determined period of time required to stabilize the sample's water saturation. The video capture system in a real-time environment traces the position (the coordinate) of the water meniscus in the water collecting measuring cell placed in the bowl with a sample.

Upon the cycle completion, the change in the volume of the water withdrawn from the sample shall be registered, and the process shall be repeated at a higher rotation level.

Set the prepared samples into the centrifuge bowl, balance the bowls' weight with the error equal to or below ± 0.05 g.

Screw the bowl assembly in the rotor. It is necessary to control that the bowl windows are oriented perpendicular to the floor surface. Afterwards shut off the vacuum in the centrifuge's testing camera (the vacuum is on by default) and place the rotor with the bowls in the centrifuge.

Start the centrifuge control program. Insert the necessary data, including sample parameters (number, length and pore volume), fluid density and the measuring cell inner diameter in the relevant field in the data window.

In the Testing tab of the Sample Info window insert the selected values of the number of rotation. In the Equilibrium tab select the sample centrifuging time at each number of rotations and checking time of the sample water saturation stabilization in accordance with Table 2. Start the trial by consecutive press of Skip Fluids Run and Start Sample Run buttons.

Table 2
Sample centrifuging time at each point depending on permeability

No.	Sample permeability Кпр, мД	Centrifuging time, t, hrs
1	0.3÷10	6÷8
2	10÷100	4÷6
3	>100	2÷4

Upon the trial completion ensure that all data are inserted in the relevant folder on the hard disk drive. Afterwards stop the centrifuge by pressing the Stop button in the Sample Info window (the Testing tab) and then the Stop button in the Centrifuge Communications window. Remove the samples from the bowls and weigh them.

Weigh the samples and register the weighing results in the laboratory log to the accuracy of $\pm 0,001$ g. Draw up a compliance table for ultracentrifuge rotary speed values and water meniscus coordinates in the water collecting measuring cell. Calculate sample water saturation factor for each rotary speed using the formula below:

$$K_{ei} = \frac{(X_i - X_0) \cdot \alpha \cdot D^2 \cdot \pi}{4},$$

where: X_0 - initial water meniscus coordinate in the measuring cell, pixel;

X_i - water meniscus coordinate in i (the centrifuging mode, pixel, corresponding to the pre-set value of the rotary speed);

α - length in pixels to length in centimeters conversion factor;

D - measuring cell inner diameter, cm.

The design of the capillary pressure curves based on the measuring results of the average water saturation of the sample and rotary speed shall be carried out with the use of branded software.

For ACES 200 ultracentrifuge, PORCAP program from PORLAB software package designed by D&E Ruth Enterprises shall be used.

For URC-628 ultracentrifuge, Centrifuge Data Analysis program shall be used.

Calculation results shall be inserted in an xls-file. Based on the obtained data, a dependency diagram for rock sample water saturation factor (K_B) and capillary pressure P_K shall be built.

6.3. Determination of rock wettability (by USBM or Ammot methods)

The method provides for the determination of the parameter, which stands for a rock wettability integral characteristic. A rock sample saturated with residual water (K_{B01}) and oil shall first be centrifuged in water up to residual oil saturation (K_{H0}) using several rotary speeds, which results in a capillary pressure curve ($KKД1$). Then the K_{H0} sample shall be centrifuged in oil up to residual water saturation (K_{B02}) (a secondary drainage). The correlation of the areas limited by secondary drainage capillary pressure curves ($KKД$) in the interval from K_{H0} to K_{B02} and imbibition in the interval from K_{B01} to K_{H0} is a wettability level indicator. The logarithm of correlation of the area under the secondary drainage curve to the area under the imbibition curve is used as a wettability index (I_u).

6.4. Nuclear magnetic resonance analysis of core samples in weathering conditions

Nuclear magnetic resonance is based on electromagnetic energy absorption during the interaction of hydrogen atomic cores (protons) as a component of water and HC with a strong constant magnetic field and a weak variable field in broadside direction to the constant magnetic field. In the constant magnetic field the resultant moment is determined by the time constant of longitudinal relaxation T_1 . In the variable magnetic field during impulse action proton magnetic moments rotate around the

constant magnetic field, which rotation attenuates in time with the time constant of longitudinal relaxation T_2 . The result of processing of the registered NMR signal describes NMR signal distribution by longitudinal relaxation times T_2 corresponding to different fluid relaxation velocities in pores of various sizes. In its physical sense, this dependency represents a differential distribution of porosity from longitudinal relaxation time T_2 .

The fundamental principle of NMR interpretation is a cut-off method. Relaxation time $T_2=3$ ms corresponds to the porosity filled with clay bound water; relaxation times $T_2=33$ ms and $T_2=92$ ms (called “ T_2 boundary” or “ T_2 cut-off”) correspond to the porosity filled with capillary bound water in terrigenous and carbonate rocks accordingly; for real rocks specified T_2 boundary values differ from specified values and are subject to adjustment by NMR core analysis. The base condition to determine T_2 boundary is the correlation of T_2 spectrum at 100% water saturated sample and T_2 spectrum obtained from a sample with residual water saturation. Internationally, pressure P_c in the water-gas system is 0.7 MPa, and it is recommended to clarify the pressure P_c depending on the free water level. Relaxation time exceeding $T_2=750$ ms corresponds to cavity porosity.

6.5. Determination of distribution slowness of shear and compressional waves in compliance with reservoir pressure conditions

Measuring rock acoustic properties is based on the solid body’s capacity to transmit compressional and shear acoustic waves excited by an external vibration source.

The subject matter of the method is to measure the elastic ultrasonic longitudinal and shear vibratory impulse time on the rock model and determine compressional and shear wave distribution velocities. The properties of the acoustic wave distributed through the sample are associated with the sample’s density and elastic properties. In particular, based on compressional and shear wave transit time, elastic constants of a solid body may be determined, such as Young modulus, Poisson ratio, shear elasticity and volume compressibility modulus.

7. Geomechanics studies

D7012-14 “Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures”

7.1. Determination of ultimate rock pseudo-triaxial compression stress including reservoir temperature modeling

7.2. Determination of elastic moduli by static and dynamic methods under pseudo-triaxial compression including reservoir temperature modeling

7.3. Determination of rock strength certificate with possible reservoir temperature modeling (Mohr's stress circles)

8. Physical and hydrodynamical studies

8.1. Determination of residual oil saturation and oil displacement factor

- 8.2. Determination of relative phase permeability in oil-water and oil-gas systems
- 9. Geochemical studies
 - 9.1 Kerogen, asphalten and rock sample pyrolysis, including determination of total organic carbon and mineral carbon content