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A new approach to the study of a representative anisotropic core sample and two-phase flow in anisotropic filtering porous environments

Theoretical analysis

The modern state of oil production is characterized by the increase in heavily recoverable reserves of hydrocarbons. Therefore new technological processes are used for hydrocarbon recovery and their efficiency is related to a more adequate description of the formation, including allowing for anisotropy of filtration-volumetric properties of the formation. Let's consider the generalization of classical models of the theory of one- and two-phased flow of immiscible fluids, based on the tensor representation of the absolute and phase permeability coefficients in anisotropic porous media which is typical for real hydrocarbon reservoirs.

Measuring the elastic properties of core material seems to be the most efficient method of establishing the fact of anisotropy of filtration-volumetric properties (FVP) and determination of the anisotropy type (symmetry of FVP of real hydrocarbon reservoirs).

In the simultaneous flow of two immiscible fluids (e.g., oil and water) it's accepted, that the Darcy law is kept for each phase and has a form:

$$
W_i^{\alpha} = \frac{K_{ij}^{\alpha}}{\mu_{\alpha}} \Delta_j p^{\alpha}, \alpha = 1,2
$$
 (1)

where:

- $\frac{K_{ij}^{\alpha}}{N}$ components of symmetric tensors of 2nd rank-phase $\frac{1}{2}$ permeability,
	- W_i^{α} components of phase filtration velocity vector,

 μ_a – dynamic viscosity coefficient,

 p^{α} – pressure in phases.

In equ. (1) and in the following the greek letters (subindices) denote a phase number and the latin letters (subindices) denote the components of vectors and tensors. The recurrent latin letters imply summation, summation is not taken with respect to the greek (indices). For convenience the tensors and the vectors are written in cartesian coordinates. Equation (1) introduces new material characteristics K_{ij}^{α} , called phase permeability. α range of α is determined by an indices). For constructions of α

Since phase permeability depends on porous space and
Since phase permeability depends on porous space and phase distribution in pores (i.e., on saturation), then initially the separation of these properties is expressed as the linear relationship between K_{ij}^{α} and the absolute permeabil-
ity tensor K_{ij} [1]: 11 11 1 12 2 13 3 *K K K K* ξ ξ ξ = + + ity tensor *Kij* [1]: ,p 1,2 form of relationship (3) is determined by an interesting the symmetry depends on potous space and $\frac{1}{2}$ it's necessary first to define tensor components of abso-

ξ ξ ξ

= + +

$$
K_{ij}^{\alpha} = f^{\alpha}(S)K_{ij} \tag{2}
$$

is put as identical. $\frac{1}{2}$ and $\frac{1}{2}$ are assumed as 23 41 1 42 2 43 3 where relative phase permeability $f^{\alpha}(S)$ are assumed as 33 31 1 32 2 33 3 *K K K K K K <i>K K* relationship between ^α *Kij* and the absolute permeability tensor *Kij* [1]: s identical intervals on porous space and phase distribution in porous space and phase distribution in porous s

Later it was shown theoretically [5, 4, 7] and confirmed experimentally [8], that relative phase permeability is de- $\frac{1}{2}$ and $\frac{1}{2}$ is the permeability of $\frac{1}{2}$ such that $\frac{1}{2}$ such the most general relationship between phase and absolute permeability is given by the tensor of 4th rank: experimentally $[8]$, that relative phase permeability is dependent not only on saturation, but on flow direction, and Later it was shown theoretically $[5, 4, 7]$ and confirmed ^α (*S*) are assumed as saturation universal functions and the the most general relationship between phase and absolute \mathcal{L} is was shown that rela-

$$
K_{ij}^{\alpha} = F_{ijkl}^{\alpha} K_{ki} \tag{3}
$$

where F_{ijkl}^{α} is the tensor of relative phase permeability where ^α *F klij* is the tensor of relative phase permeability coefficients with the first and second

coefficients with the first and second pair of indices symmetric even when rearranged. troduces new material characteristics ^α *Kij* , called phase permeability.

Alongside it, the elastic properties of media are de-
symmetry. In figure 1 there's scribed by Hook's law \int $\frac{1}{2}$ $\frac{1}{$

$$
p_{ij} = C_{ijk} \varepsilon_{kl} \text{ or } \varepsilon_{ij} = S_{ijkl} p_{ij}
$$

where

 p_{ii} – components of stress tensor;

 ε_{kl} – components of deformation tensor;

 C_{ijk} and ε_{kl} are components of the tensors of 4th rank.

The 4th rank tensors F_{ijk}^{α} , prescribing relative phase permeability, are the same rank and the same internal **permeability** coefficients with the first and second internal symmetry as the tensors of the elasticity coefficients $C_{ij\,kl}$ or elastic pliability S_{ijk} in Hook's law.

Explicit form of the tensors $C_{ij\;kb}$, $S_{ij\;kl}$ is determined by the symmetry group of elastic properties, in which case the symmetry group of tensors $C_{ij \, kl}$, $S_{ij \, kl}$ and $F_{ij \, kl}$ coincide. The symmetry of elastic properties can be determined by the form of tensor surfaces. In particular, the values reciprocal to Young's modulus, $E(n_i)$, in the direction n_i are determined by formula

$$
E^{-1}(n_i) = S_{ij\;kl} \; n_i \; n_j \; n_k \; n_l
$$

Therefore using conventional methods for the determina-

and second pair of indices sym-
for the cross-section of tensor surface; for example, from the rearranged. Increase properties is expressed as the separation of the core's axis of symmetry, and define their symmetry. In figure 1 there's a photograph of the device, measuring the ultrasound wave velocity through the porous media.

^α (*S*) are assumed as saturation universal functions and the ties are shown. The direction of the extreme properties $(\text{minimum and maximum})$ is determined by the measured It suess tensor, data, and then the samples of smaller dimensions are cut of deformation tensor, out from the sample core along the extreme directions for In fig. 2 the measuring results of core elastic properthe carrying out of hydrodynamic studies.

tion of elastic characteristics one can measure elastic properties **Election of elastic characteristics** one can measure elastic properties ultrasound wave velocity through a porous material *E*-1 (*ni*) = *Sij kl ni nj nk nl* ultrasound wave velocity through a porous material Fig. 1. The device «Uzor 2000» for measuring of $\frac{1}{1}$

Fig. 2. Section of the surface of elastic properties measured along the lateral surface of the core-sample

\blacksquare k nown and the problem of all six tensor components of the permeability of the p **The symmetry type principle of filtration properties**

of the 2nd rank tensors of is unknown and the problem all si of determination of all six tensor components of the six measurements, obtained along six independ permeability coefficients reduces. Therefore the mini-
directions. coefficients reduces. Therefore the minimum number of measurements equals 6. In prin-A) In the most general case the position of the main axes

coefficients reduces. The minimum number of minimum number of minimum number of measurements equals 6. In prinmum number of measurements equals 6. In principle all six components can be determined by the data of six measurements, obtained along six independent directions.

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- B) In the next case with a descending level of complexity is needed to determine four components of tensor permeability. In this case the position of one of the main axes is known and it's necessary to determine the position of two other axes (one rotation angle of the laboratory coordinate system Oxyz around the known main axis), and three main tensor components of permeability. Thus, the minimum number of measurements needed equals 4. In fig. 3c the surface section of elastic properties for cases A and B is shown.
- C) For porous media with orthotropic filtration properties the position of all the main axes is known. Therefore for the specification of filtration properties, three main values of tensor permeability would be enough. The problem is solved by three measurements, obtained — cut samples, core handling and obtaining the permeabi along the main directions. In fig. 3b the section of the elastic properties for case C is shown.
- D) For transversal-isotropic material the problem is reduced even more: it's necessary to determine only the two main values of tensor permeability. The minimum number of measurements equals two. Measurements are made in an isotropy plane of filtration properties and in the direction normal to it. In fig. 3a the section surface of elastic properties for case D is shown.

The principle determination schemes of permeability anisotropy in one- and two-phase fluid flow remain the properties for cases A and B is shown. Same in the selection of the number of cores and direcporous media with orthotropic filtration properties tions of measurements. Thus, the problem of absolute and position of all the main axes is known. Therefore relative phase permeability determination in anisotropic the specification of filtration properties, three main formations focuses on setting the symmetry of filtration properties and then at carrying out the experiments on the cut samples, core handling and obtaining the permeability $\frac{1}{2}$ and the matrixes. The determination of the RFP functions can be matrixes. The determination of the RFP functions can be realized by using the formulae proposed in [4, 5, 7]. α is the direction normal to it. In fig. 3.3 α the section surface of α and β are computed for properties α .

Fig. 3. Section of the surface of elastic properties on plane x_1x_3 in the case when the position of all main the axes is known (isotropic, transversal-isotropic and orthotropic properties)

I – figures 3a, 3b; figure 3c is a section of the surface elastic properties by the plane x_1x_2 when the position of all main axes is unknown when the position of all main axes is unknown

The sequence of performing the complex studies

e material is suggested:

e material is suggested:
 carrying out the cut samples and discussed the experiment of the test data some check samples -volumetric properties, the following working plan for real are determined using conventional methods, core material is suggested:

- by ultrasonic wave velocities and elastic properties measurement, $\frac{1}{4}$ $\frac{1}{4}$. $\frac{1}{4}$. $\frac{1}{4}$. $\frac{1}{4}$. $\frac{1}{4}$.
- the symmetry (anisotropy type or isotropy) of the core filtration properties is determined by the symmetry of same elastic properties,
- the number and the directions of core sample cutting out are determined depending on symmetry type stants are determined using the explicit form of relation properties is determined using the explicit form of relation properties is determined using the explicit form of (fig. 4), $\mathfrak{g}_{\mathfrak{p}}$
- for each sample the absolute permeability coefficients are determined using conventional methods, Finally, to perform the complex studies of filtration- • for each sample the absolute permeability coefficient
- can be prepared; test data obtained from the check samples can be recalculated using «base» measurements and allow error estimation, • the symmetry of elastic core properties is determined **and the RFP** function of the rest data some check said.
• the symmetry of elastic core properties is determined can be prepared; test data obtained from the cl
	- metry (anisotropy type or isotropy) of the core
 \bullet after absolute permeability tensor is determined the same samples are used for laboratory measurements elastic properties, of relative e phase permeability functions,
		- laboratory test data are processed and empirical constants are determined using the explicit form of relative phase permeability functions.

artykuły iest data are processed and empirical constants are determined using the expliand absolute permeabilities and the laboratory method for the determination of non-diagonal tensor components of p arry k uty. The monoclinic symmetry \mathcal{L}

Below we'll consider an explicit representation of the laboratory method is and the determination of the determinatio relation (3) between the phase and absolute permeabilities \blacksquare and the laboratory method for the determination of nondiagonal tensor components of phase permeability for $\left\langle \left\langle \right\rangle \right\rangle$ media with monoclinic and triclinic symmetry. $\left\langle 4\right\rangle$

Fig. 4. Scheme of the core-sample cut out

α and absolute nermeabilities relation to to with triclinic symmetry of filtration properties Representation of phase and absolute permeabilities relation to tensor components of phase permeabilities
المستعدد وفياء المناطق **phase permeabilities with triclinic symmetry of filtration properties**

Explicit form of relationship (3) is determined by anisotropy type (symmetry group) of filtration properties.

In the case of triclinic symmetry of filtration properties the position of the main axes of tensors K_{ij}^{α} and K_{ij} is un-
will be characterized by all six non-zero con After all the tensor K_{ij} components are determined it can permeability tensors symmetry. written in the main axes. The relationship get simplified interest, is when limiting values be reduced at the main axes. Then relationship (3) can be For solution of the applied pr known, therefore these tensors contain all six components. Hence, the symmetry of the filtration For transformation of the relationship (3) it's necessary K_{ii}^{α} and K_{ij} may not coincide. In which first to define tensor components of absolute permeabilities. permeability tensors symmetry sho and take a form: the main axes. Then relationship (3) can be For solution of the applied problems, a case of great In the case of trictime symmetry of filth In the tensor \mathbf{x}_{ij} components are determined it can betthe ability tensors symmetry. laboratory test data are processed and V is $m = \frac{m}{\ln n}$ constants at $\ln n$ and $\ln m$ sition of the main axes of tensors K_{ij}^{∞} and K_{ij} is un-
will be c

$$
K_{11}^{\alpha} = \xi_{11}^{\alpha} K_1 + \xi_{12}^{\alpha} K_2 + \xi_{13}^{\alpha} K_3
$$
 this particular case. The general form of the relative phase
\n
$$
K_{22}^{\alpha} = \xi_{21}^{\alpha} K_1 + \xi_{22}^{\alpha} K_2 + \xi_{23}^{\alpha} K_3
$$
permeability functions (4) can be written as:
\n
$$
K_{33}^{\alpha} = \xi_{31}^{\alpha} K_1 + \xi_{32}^{\alpha} K_2 + \xi_{33}^{\alpha} K_3
$$
 (4)
\n
$$
K_{12}^{\alpha} = \xi_{41}^{\alpha} K_1 + \xi_{42}^{\alpha} K_2 + \xi_{43}^{\alpha} K_3
$$
 (4)
\n
$$
K_{12}^{\alpha} = \xi_{51}^{\alpha} K_1 + \xi_{52}^{\alpha} K_2 + \xi_{53}^{\alpha} K_3
$$
 (5)
\n
$$
K_{12}^{\alpha} = \xi_{61}^{\alpha} K_1 + \xi_{62}^{\alpha} K_2 + \xi_{63}^{\alpha} K_3
$$
 (6)
\nwhere $\varphi_i^{\alpha} = K_i^{\alpha} / K_i$, $\theta_{ij} = K_i / K_j$.
\nEqu. (5) should satisfy the following conditions: when

where ξ_{mn}^{α} are tensor components of relative phase perme-
 $S = S(i)^*, \varphi_i^1 = 0$, and when $S = S^*(i)$, $\varphi_i^2 = 0$. abilities in the coordinate system, coinciding with the main that all the functions are of the s symmetry groups. Indeed, assuming that all the tensor components and all the tensor components and are non-zero, then are non-z axes of the absolute permeability tensor; K_i are main values of the absolute permeability tensor. axes of the absolute permeability tensor; K_i are main val-

 ω $\alpha^1 = \frac{I_1(K)}{K_1} \cdot \xi_2 \cdot (S - S(i))$ Using relationship (4) it can be shown, that tensors K_{ij}^{α} $L(K)$ (b) $L(K)$ (c) (c) and K_{ij} can belong to different symmetry groups. Indeed, $\varphi_i^1 = \frac{2\pi i}{K_i} \cdot \xi_{ii} \cdot (S - S(i))^*$ assuming that all the tensor components ξ_{mn}^{α} are non-zero, then tensors K_{ij}^{α} and K_{ij} have different symmetry axes. $\varphi_i^2 = \frac{I_1(K)}{K} \cdot \xi_{ii} \cdot (S(i) * -S)$ (6) Moreover, the symmetry of tensor K_{ij} can be increased K_i from triclinic to orthotropic one and then to transversal-
where summation with respect to $\left(\frac{1}{2}\right)$ Explicit form of relationship (4) it can be shown, that tensors K_{ij}^{α} $I_1(K)$ $I_2(K)$ K α conditions and corresponding to the common approximation of α relative phase permeability for α

phase permeabilities with triclinic symmetry of filtration properties Explicit form of \mathbb{R}^n is determined by an- \mathbb{R}^n is determined by an- \mathbb{R}^n type (symmetry group) of \mathbb{R}^n is determined by anof filtration properties meability tensors will have triclinic symmetry, i.e. they s of tensors K_{ij}^{α} and K_{ij} is un-
will be characterized by all six non-zero components. s contain all six components. Hence, the symmetry of the filtration properties tensors of the relationship (3) it's necessary K_{ij}^{α} and K_{ij} may not coincide. In which case relative phase nts of absolute permeabilities. permeability tensors symmetry should coincide with phase laboratory test data are processed and empirical constants are determined using the explined by an-
isotropic and isotropic, successively supposing that erties. $K_1 = K_2 \neq K_3$ and $K_1 = K_2 = K_3$. In any case the phase per- E_{max} is determined by animalizing group) is determined by anisotropy type (symmetry group) of \mathcal{L}_{max} d it can permeability tensors symmetry. $\begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$ $\begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix}$ $\begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix}$ the main position of the main axes the position of the main axes of the m

explicit form for relative phase permeability functions for explicit form for relative phase permeability functions for $\frac{1}{2}$ main axes. The relationship get simplified interest, is when limiting values of saturations differ from lute permeabilities. After a component and the tensor **King of the tensor of substances** of and take a form:
and take a form:
 $\frac{1}{2}$ and 1. Therefore let's consider the generalization of χ ₃ this particular case. The general form of the relative phase K_3 permeability functions (4) can be written as: $K_{11}^{\alpha} = \xi_{11}^{\alpha} K_1 + \xi_{12}^{\alpha} K_2 + \xi_{13}^{\alpha} K_3$ error and the particle of the second of periodic process of $K_{21}^{\alpha} = \xi_{11}^{\alpha} K_1 + \xi_{12}^{\alpha} K_2 + \xi_{23}^{\alpha} K_3$ se. The general form of the relative phase $\frac{1}{2}$ for solution of the application of the detail vertical problems. $R^a = \frac{\mu}{\mu}$ $\mu = \frac{\mu}{\mu}$ $\mu = \frac{\mu}{\mu}$ and $\mu = \frac{\mu}{\mu}$ ar form of the relative phase Fitten as: $\frac{d}{dx}$ *t* is particular case. The general form of the relative phase *k k Can k* α and α and α and α and α meability fu

$$
\xi_{32}^{\alpha}K_2 + \xi_{33}^{\alpha}K_3
$$
\n
$$
\xi_{42}^{\alpha}K_2 + \xi_{43}^{\alpha}K_3
$$
\n
$$
(4) \qquad \qquad \varphi_i^{\alpha} = \xi_{ij} + \xi_{ik}\theta_{ki} + \xi_{i,1}\theta_{li}
$$
\n
$$
(5)
$$

relative phase permeability functions (4) can be written as:

 $\mathbf{S} = \mathbf{N}_i / \mathbf{N}_j$. where $\varphi_i^{\alpha} = K_i^{\alpha}/K_i$, $\theta_{ij} = K_i/K_j$. \overline{K} where *^j* ^ϕ*ⁱ* = *Ki Ki* ^θ*ij* = *Ki Kj*

Figuro System, and a strategies and all the tensor components and are tensor components and are tensor components of relative permeabilities in the components of *πρ*οβλεί να το στέλει στη στέλει στη στέλει στη στέλει στη $E(qi. (3)$ should satisfy the following conditions. When
ents of relative phase perme-
 $S = S(i)^*, \varphi_1^1 = 0$, and when $S = S^*(i), \varphi_1^2 = 0$. Assuming permeability tensor; K_i are main valued be transformed in the following approximate equations: **phase perme** ∞ ∞ (v), γ_1 ∞ , and when ∞ ∞ (v), γ_1 ∞ interation the main that all the functions are of the same order, then (5) can $F_{\text{d}}(5)$ should satisfy the following conditions: when $\frac{1}{\sqrt{2}}$ ($\frac{1}{\sqrt{2}}$ that all the functions are of the same order, then (5) can
be transformed in the following amongsimum constitutions. $S = S(i)^*, \varphi_i^1 = 0$, and when $S = S^*(i)$, $\varphi_i^2 = 0$. Assuming $\frac{1}{s}$ (*s*) (*s*) $\frac{s}{s}$ *i* (*s*) be transformed in the following approximate equations: Equ. (5) should satisfy the following conditions: when *i* $S(y, y_1, y_2, y_3, y_4, y_5, y_6, y_7, y_7, y_8, y_9, y_1, y_1, y_2, y_1, y_1, y_2, y_1, y_2, y_3, y_1, y_2, y_1, y_2, y_1, y_2, y_3, y_1, y_2, y_3, y_1, y_2, y_3, y_1, y_2, y_3, y_4, y_5, y_6, y_7, y_7, y_8, y_9, y_1, y_2, y_3, y_4, y_7, y_8, y_9, y_1, y_2, y_3, y_4, y_7, y$ be transformed in the following approximate equations:

$$
\varphi_i^1 = \frac{I_1(K)}{K_i} \cdot \xi_{ii} \cdot (S - S(i)*)
$$

$$
\varphi_i^2 = \frac{I_1(K)}{K_i} \cdot \xi_{ii} \cdot (S(i) * -S)
$$
(6)

the total transversal-
where summation with respect to (i) is absent. needed to take into account the condition at another range of the interval saturation change. where summation with respect to (i) is absent.

where *^j* ^ϕ*ⁱ* = *Ki Ki* ^θ*ij* = *Ki Kj*

^α ^α , .

^ϕ*ⁱ* ξ*ij* ξ ^θ*kiik* ξ ^θ*lii*

The multipliers $(S - S(i)^*)$ and $(S^*(i) - S)$ ensure satisfac-
eters of media, and it's val tion of the above mentioned conditions and correspond to approximations the common approximation of relative phase permeability ca for isotropic porous media. The multiplier $I_1(K)/Ki$, where $I_2(K)$ is a first investigate of absolute a sumpositive tensor is $I_1(K)$ is a first invariant of absolute permeability tensor, is due to anisotropy. Then, for approximation of the functions, it's needed to take into account the condition at another range of the interval saturation change. Initially the phase function can be represented range of the mervar saturation change. Initially the phase tranction can be represented as.
permeability functions were constructed in the interval $S^* \leq S \leq 1$ (for water) and $0 \leq S \leq S^*$ (for oil or gas). In this case φ^{α} values at the interval boundaries were fixed: $\varphi_i^1(1)=1$ K^1 formed in the following approximate equations: where summation with respect to (*i*) is absent. $S^* \leq S \leq 1$ (for water) and $0 \leq S \leq S^*$ (for oil or gas). In this (for water) and $\varphi_i^2(0) = 1$ (for oil or gas). Recently the mea-
 $K_{ij}^1 = \left| \alpha_{ij} + \left\{ \frac{1}{3k_3} - 1 \right\} \left| S_{(ij)} - S \right| \right|$ (for water) and φ_i (0)=1 (for on or gas). Recently the mea-
surements have been performed in the mobility interval for both phases $S^* \le S \le S^*$. Therefore the $\varphi_i^1(S = S^*)$ values $\left(\frac{S - S(ij)^*}{S}\right)$ (for water) and $\varphi_i^2(S = S^*)$ values (for oil and gas) transform $\left(\frac{\overline{S_{(ij)}^*} - S(ij)^*}{\overline{S_{(ij)}^*} - S(ij)^*}\right)$ in the values «at free range» and are determined experiment tally. Thus, it's needed that the initial relative phase perme-
 $K_{ii}^2 = \left[b_{ii} + \left\{ \frac{I_i(k)}{(s-1)} \right\} \left(S - S(ij) \right) \right]$ to anisotropy and equals 1 for in the case of anisotropic media, then in the case of \mathbb{R}^n ability representation ψ is ψ in ψ mentioned conditions, can be above me $\frac{1}{a}$ FIELENDIC, assuming that intuitiplier $T_1(x) F_{\gamma/\alpha}$ in (0) is due to
anisotropy and equals 1 for isotropic media, then in the cas refore, assuming that multiplier $I_1(k)F/k_\alpha$ in (6) is due t The
anis $\frac{1110}{201}$ *^S iS ^S ^S c* can be presented otropy the relative phase permeability function ŗ representation, satisfying the repres
can be Initially the phase permeability functions were constructed in the interval *S** ≤ *S* ≤ 1 (for waability representation $\varphi = [(S - S^*)^{\epsilon}/(1 - S^*)]$ for isotropic $K_{ij}^2 = \begin{bmatrix} b_{ij} + \begin{cases} \frac{\gamma}{2} & i \neq j \\ 3k_{\epsilon} & 1 \end{cases} \end{bmatrix}$ Therefore, assuming that multiplier $I_1(k)F/k_\alpha$ in (6) is due to $\left(\frac{S_{(ij)}^*-S}{S_{(ij)}-S_{(ij)}}\right)^{\beta_{ij}}$.
 k_e – for oil (gas) * $\frac{1}{2}$ ($\frac{1}{2}$) ($\$ for *I sociople meand*, *inch in* the case of *i*otropy the relative phase permeability functions *K* the common approximation of relative phase permeability case. $\frac{1}{1}$ is a *i* is a and w annouply. Then, for approximation of the functions, the general case of it s needed to take into account the condition at another the approximation of relative phase permeability for $\frac{\alpha}{\alpha}$ into account the condition at another range of the interval saturation change of the interval saturation change. $3 \cdot 53 \leq t$ (for water) and $0 \leq s \leq 3$ (for on or gas). In this phase personality functions $\lim_{n \to \infty} \frac{f(x)}{f(x)} = \lim_{n \to \infty} \frac{f(x)}{f(x)} = \lim_{n \to \infty} \frac{f(x)}{f(x)}$ media Therefore, assuming that multiplier
anisotropy and equals 1 for isotropic anisotropy and equals 1 for isotropic media, then in the case $\left(\frac{w}{S_{(ij)}^* - S(ij)^*}\right)$ $\cdot k_e$ - for oil (gas) ansolopy and equals 1 for isotropic fried $\overline{1}$ ľ ng the abo representation, satisfying the above mentioned conditions, can be presented as: $\mathcal{L}(\mathcal{A})$ \ddot{x} is needed to It s needed to take mit account the condition at another $S^* < S < 1$ (for water) and $0 < S < S^*$ (for oil or gas) In this needed to take into account the condition at another range of the interval saturation change. $\cos \varphi$ values at the interval boundaries were fixed. φ_i (f)= $\overline{}$ to and the proposed by $a^1 = \alpha^1 (s - s)^1 \hat{f}$, $\hat{f}(\hat{s}^* - s)^1 \hat{s}$ phase permeability $\gamma_i = \alpha_i$ to $\rho(\mu_{jk})$ in $\rho(\mu_{jj})$. *i* $\overline{}$ anisotropy and equals 1 for isotropic media, the
of anisotropy the relative phase permeabi β e
A $\overline{1}$ an be pre $\frac{1}{2}$ can be presented as: w_i is $\frac{1}{i}$ is $\frac{1}{i}$ integration with respect to $\frac{1}{i}$ anisotropy. I hen, for approximation of the functions, the general case of triclinic
eded to take into account the condition at another ties the approximations of $\frac{1}{2}$ into account the condition at another range of the interval saturation change. $\frac{1}{2}$ case φ^{μ} values at the interval boundaries were fixed: $\varphi_i^{\mu}(1)=1$
(for water) and $\varphi_i^2(0)=1$ (for oil or gas). Becausily the mean $K_{ij}^1 = |\alpha_{ij}| + \left| \frac{I_i(k)}{3k} - 1 \right| \left| \left(S_{(ij)}^* - S \right) \right|$ to an integration and equal in the case of $\frac{g(t) \hat{f}(t)}{g(t)}$ is the relative relative the relative relative relative to the relative relat ability representation $\varphi = [\underline{s} - s^x]/(1 - s^x)]$ for isotropic
media to be replaced by $\varphi_i^1 = \alpha_i^1 (S - S(i))^{k_i} / (S(i) - S(i))^{k_i}$. $\frac{1}{\sqrt{1}}$ *i* \overline{a} nase per Į. l. the must are permeable to the relative phase permeable f anisotropy the relative phase permeable anisotropy and equals 1 for isotropic media, then in the case
of anisotropy the relative phase permeability functions ntioned conditions, when can be presented as: $\begin{aligned}\n\text{ment} \\
(i = i)\n\end{aligned}$ The multipliers $(S - S(i)^*)$ and $(S^*(i) - S)$ ensure satisfac-
eters of media, and it's value should correspo due to anisotropy. Then, for approximation of the functions, the general case $\begin{bmatrix} 1 & 0 \ 0 & 0 \end{bmatrix}$ (*K*) is a first invariant of absolute *I*₁ (*K*) is a first invariant of absolute *I*₁ both phases $S^* \le S \le S^*$. Therefore the $\varphi_i^1(S = S^*)$ values $\left(\frac{S - S(ij)^*}{S^* - S(j)}\right)^{1/2} \cdot k_e$ – for water ï \mathfrak{z} \overline{a} b t. d cond or amsoropy the relative phase permeability functions
representation, satisfying the above mentioned conditions, where when $i \neq j$ the indexes i, j, l form a cyclic
can be presented as: the above mentioned conditions, where when $i \neq j$ the indexes i, j $I_1(K)$ is a first invariant of absolute permeability tensor, is for isotropi *K i* it's needed to take into account the condition at another ties the approxi range of the interval saturation change. Initially the phase function can be represented as: $\frac{1}{1}$ is a summation with respect to $\frac{1}{1}$ is absent. The summation $\frac{1}{1}$ is absoluted to $\frac{1}{1}$ is absoluted to $\frac{1}{1}$ is absoluted to $\frac{1}{1}$ is absoluted to $\frac{1}{1}$ is a set of $\frac{1}{1}$ is a set (for water) and φ_i^2 ($S = S^*$) values (for oil and gas) transform $\left(\frac{S_i^*}{S_{(ii)}^* - S(i)}\right) \rightarrow k_e$ - for water $\left(\begin{array}{cc} \Sigma_{ij} & \Sigma_{ij} & \Sigma_{ij} \end{array} \right)$ (see Fig.) were constructed in the interval $\left(\begin{array}{cc} S_{ij} & \Sigma_{ij} & \Sigma_{ij} \end{array} \right)$ $\frac{1}{2}$ skat free range*»* and are determined experimenanisotropy and equals 1 for isotropic media, then in the case $\left(\begin{array}{c} S_{(ij)} - S_{(ij)} \end{array} \right)$ the common approximation of relative phase permeability case. for isotropic porous media. The multiplier $I_1(K)/Ki$, where Traditio $S^* \leq S \leq 1$ (for water) and $0 \leq S \leq S^*$ (for in the values «at free range» and are determined experimention of $\left(\begin{array}{cc} 0 & 0 & 0 \\ 0 & 0 & 0 \end{array}\right)$ tally. Thus, it's needed that the initial relative phase perme-
 $\begin{bmatrix} I_k \\ I_l \end{bmatrix}$ $\begin{bmatrix} I_l(k) \\ I_l \end{bmatrix}$ $\begin{bmatrix} I_l(k) \\ I_l \end{bmatrix}$ $\begin{bmatrix} I_l(k) \\ I_l \end{bmatrix}$ any. Thus, it s needed that the initial relative phase perme-
 K_{ii}^2 = ability representation $\varphi = [(S - S^*)^{\epsilon}/(1 - S^*)]$ for isotropic $K_{ij}^2 = \begin{bmatrix} b_{ij} + \begin{cases} \frac{2}{3}k_{\epsilon} \\ 3k_{\epsilon} \end{cases} - 1 \end{bmatrix} (S - S(ij))^*$ abouty representation $\varphi = [\sqrt{5-5} \tbinom{1-5}{1} \tbinom{1-5}{i} \tbinom{1-5}{i}$ Therefore, assuming that multiplier $I_1(k)F/k_\alpha$ in (6) is due to $\left(\frac{S_{(ij)}^* - S}{\sigma^* - S_{(ij)}}\right)^{1/\alpha} \cdot k_\alpha$ - for oil (gas) representation, satisfying the above mentioned conditions, where when $i \neq j$ the indexes i, j, l form a cycl the saturation of $S^1(t) - S$ saturations differentially differentially and the system of explicitly correspondent it's needed to take into account the condition at another ties the approximations of the relative phase $\cos \varphi^{\alpha}$ values at the interval $S^* \le S \le 1$ (for water) and $0 \le S \le S^*$ (for oil or gas). In this (for water) and φ_i^2 ($S = S^*$) values (for oil and gas) transform $\left(\frac{S'(x)}{S_{(ij)}^* - S(ij)^*}\right)$ $\cdot k_e$ - for water Therefore, assuming that intriguor $r_1(v)$ γv_α in (c) is due to $\left(\frac{S_e}{S_{\text{min}}^*} - S(i) \right) * k_e$ = 101 011 (games of the interval saturation change. of anisotropy the relative phase permeability functions representation *φ* = [(*S* – *S**)^ε $\sum_{i=1}^{\infty}$ points. Hence, the symmetry of the filtration properties the filtration properties tensors at $\sum_{i=1}^{\infty}$ may not contain $\sum_{i=1}^{\infty}$ and $\sum_{i=1}^{\infty}$ may not computed the symmetry of the symmetry o permeability tensors symmetry. ^ϕ*ⁱ* ξ*ij* ξ ^θ*kiik* ξ ^θ*lii* permeability functions were constructed in the interval
 $\mathbb{R} \times \mathbb{R} \times \mathbb{R}$ $\frac{11}{\sqrt{11}}$ $\frac{11}{\sqrt{11}}$ $\frac{11}{\sqrt{11}}$ $\frac{1}{\sqrt{11}}$ tany. Thus, it s needed that the initial relative phase perme-
K of anisotropy the relative phase permeability functions formed interval formed interval formed $f(x) = \frac{1}{2}$ s $\frac{1}{2}$ i $\frac{1}{2}$ $\frac{$ $\frac{1}{2}$ is common upproximation anisotropy and equals 1 for isotropic media, then in the case $S_{(ij)}^* - S(ij)^*$ can be presented as. ial relative ph permeability tensor, is due to anisotropy. Then, for approximation of the functions, it's *i* **determined experiment**
 i **I** *c i******s i <i>k***
i s <i>k i s <i>k***i <i>k <i>k i <i>k <i>k <i>i <i>k <i>k***
***<i>k <i>k <i>k <i>k <i>k <i>k* $\left[1 - S^* \right]$ for isotropic *^S ijS ^k* fore, assuming that multiplier $I_1(k)F_\gamma/k_\alpha$ in (6) is due to $\left(\frac{S_{(ij)}^* - S}{S_{(ij)}^* - S_{(ij)}^*}\right)^{p_{ij}} \cdot k_e$ – for oil (ga ropy and equals 1 for isotropic media, then in the case $\left(\frac{s_{ij}}{S_{(ij)}^* - S(ij)^*}\right)$ $\cdot k_e$ - for oil (gas) $\frac{1}{2}$

ponents. Hence, the symmetry of the filtration properties tensors ^α *Kij* and *Kij* may not coin-

tensors will have triclinic symmetry, i.e. they will be characterized by all six non-zero com-zero com-zero co

$$
\varphi_i^1 = \begin{bmatrix} \alpha_i + \begin{bmatrix} I_1(k) \\ 3k_i \end{bmatrix} - 1 \end{bmatrix} \begin{bmatrix} S_{(i)}^* - S \end{bmatrix}
$$
\n
$$
\left[\begin{array}{c} S - S(i)* \\ S(i) - S(i)* \end{array} \right]
$$
\n
$$
= \begin{bmatrix} 5 - S(i)* \\ S(i) - S(i)* \end{bmatrix}
$$
\nFor water
\nTherefore, the non-diagonal component of K_{ij}^{α} -tensor. This approach is impossible
\ntherefore the non-diagonal component of K_{ij} -tensor equals zero.
\nTherefore, the following equation is a function of the non-diagonal component of K_{ij} -tensor equals zero.

$$
\varphi_i^2 = \left[b_i + \left\{ \frac{I_1(k)}{3k_i} - 1 \right\} (S - S(i) *) \right]
$$
\ncomponent is obtained by division by one of the main components of K_{ij} -tensor. In eq. (9) there's one of the possible variants in *i*, *j*, *l* – indices forming cyclic rearrangement.

\n
$$
\left[\frac{S_{(i)}^* - S}{S_{(i)}^* - S(i) * } \right]^{\beta}
$$
\nfor oil or gas

\n(8)

\n(8)

\n(8)

\n(9)

\ndetermine phase permeability for triclinic symmetry *l* - indices forming cyclic rearrangement.

\nend phase permeabilities for all anisotropy types (symmetry)

where α_i , b_i , ε_i , β are parameters experimentally determined; symmetry it's needed to set $k_1^{\alpha} = k_2^{\alpha} = 0$ in e in which case $\alpha_i = \varphi_i^1(S_{(i)}^*)$, $b_i = \varphi_i^2(S(i))^*$.

> That the indices ε_i and β_i should be represented through versal – isotropic symmetry it's needed to add invariant values defining the filtration-volumetric param-
 $k_{11} = k_{22}$ to the latter condition. *tg* − ∪ ∪ ∪ + (10)

 $\frac{1}{S^*(i)-S}$ ensure satisfacters of media, and it's value should correspond to known inility case. above mentioned conditions and correspond to approximations in going from anisotropy case to isotropic
and connective of relative above assessability.

where $\frac{1}{10}$ is the summation we have the construction with respect to $\frac{1}{10}$ is a particular to $\frac{1}{10}$ $\frac{1}{2}$ for isotropic means is a particular case for $\left(7\right)$, $\left(0\right)$, $\frac{1}{2}$ or approximation of the functions, the general case of triclinic symmetry of filtration properties the approximations of the relative phase permeability has been ability tion change. Initially the phase function can be represented as: needed to take into account the condition at another range of the interval saturation change. porous media. The multiplier $I_1(K)/Ki$, where Traditional relative phase permeability representation absolute permeability tensor, is for isotropic media is a particular case for (7) , (8) . For That the indices *εi* and *βi* should be represented through invariant values defining the nal relative phase permeability representation

(for water) and
$$
0 \le S \le S^*
$$
 (for old or gas). In this
ues at the interval boundaries were fixed: $\varphi_i^1(1)=1$

\nand $\varphi_i^2(0)=1$ (for oil or gas). Recently the mea-
have been performed in the mobility interval for
s $S^* \le S \le S^*$. Therefore the $\varphi_i^1(S = S^*)$ values

\nand $\varphi_i^2(S = S^*)$ values (for oil and gas) transform
s \langle at free range ω and are determined experiment.
it's needed that the initial relative phase perme-
resentation $\varphi = [(S - S^*)^{\circ}/(1 - S^*)]$ for isotropic
to replaced by $\varphi_i^1 = \alpha_i^1(S - S(i_1))^{\varepsilon_i}/\sqrt{S_{(i)}^* - S(i_2)^*}$.

\nassuming that multiplier $I_1(k)F_1/k_{\alpha}$ in (6) is due to
and equals 1 for isotropic media, then in the case
any the relative phase permeability functions

\n
$$
\left(\frac{S_{(ij)} - S_{(ij)}}{S_{(ij)} - S_{(ij)}}\right)^{\beta_{ij}}
$$
\nand $\varphi_i^2 = \left[b_{ij} + \left\{\frac{I_i(k)}{3k_{\varepsilon}} - 1\right\}(S - S_{(ij}^*)^*)\right]$

\n(9)

\nasuming that multiplier $I_1(k)F_1/k_{\alpha}$ in (6) is due to
and equals 1 for isotropic media, then in the case

\n
$$
\left(\frac{S_{(ij)}^* - S_{(ij)}^*}{S_{(ij)}^* - S_{(ij}^*)}\right)^{\beta_{ij}}
$$

\nand k_{ε} for oil (gas)

ctions, where when $i \neq j$ the indexes i, j, l form a cyclic rearrang ented as:
the development of 1, 2, 3, and when $i = j$ all indexes are equal $(i = j = l)$; but sur $\begin{bmatrix} 1 \\ 2 \\ 3 \end{bmatrix}$ = for water (7) the non-diagonal components, because the corresponding non-diagonal component Ĵ $\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ $\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ Note, that to get relative phase permeability the diagonal $\varphi_i^1 = \left(\alpha_i + \left\{ \frac{I_1(k)}{3k}\right\} - 1 \right\} \left[\left(S_{(i)}^* - S \right) \right]$ components of K_{ij}^{α} -tensor are divided by corresponding $\begin{bmatrix} 3k_i \\ 3k_i \end{bmatrix}$ $\begin{bmatrix} (n_i) \\ (n_i) \end{bmatrix}$ components of \mathbf{A}_{ij} -tensor are divided by corresponding components of K_{ij} -tensor. This approach is impossible for sented as: ment of 1, 2, 3, and when $i = j$ all indexes are equal $(i = j = l)$; but s $(i = j = l)$; but summation with respect to i is not taken. need to the intorine conditions, where when $t \neq f$ the indexes t, f, t form a cyclic realization $\frac{f(t)}{f(t)*}$ - for water (7) and the non-diagonal component of K_{ij} -tensor equals zero. riants in *i*, *j*, *l* – indices forming cyclic rearrangement. mentioned conditions, where when $i \neq j$ the indexes i, j, l form a cyclic rearrange- T_{ij} considerations more visualized, and an analysis of the dependence visualized, and an analysis of the dependence of the depen $T_{\text{mont of 1, 2, 3}}$ and when $i = i$ all indexes are equal mentone contracts, where $\lim_{i \to \infty} f_j$ is meaned f_j , $\lim_{i \to \infty} f_j$ and $\lim_{i \to \infty} f_j$ riants in *i*, *j*, *l* – indices forming cyclic rearrangement. $\begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$ Note, that to get relative phase permeability the diagonal Note, that to get relative phase permeability the diagonal
components of K_{ij}^{α} -tensor are divided by corresponding
components of K, tensor. This approach is impossible for components of K_{ij} -tensor are divided by corresponding
components of K_{ij} -tensor. This approach is impossible for $i \neq j$ the indexes i, j, i form a cyclic rearrange-
2, 3, and when $i = j$ all indexes are equal the above mentioned conditions, where when $i \neq j$ the indexes i, j, l form a cyclic rearra-
ment of 1 2 3 and when $i = i$ all indexes are ϵ ment of 1, 2, 3, and when $i = j$ all indexes
($i = j = l$); but summation with respect to i is form a cyclic rearrange-
i all indexes are equal
espect to i is not taken $i = j$ all indexes are equal nge-
_{Gual} *I I*, *I*, *I* form a cyclic rear
n $i = i$ all indexes are $\ddot{}$ \sum omponents of K_{ij}^{α} -tensor are e presented as: ment of 1, 2, 3, and when $i = j$ all indexes are equ $(y - l), 0$ $f(x)$, and when $t = f(x)$ \mathbf{r} $\frac{1}{1}$ ⊂l omponents of K_{ii} -tensor $(i = j = l)$; but summation
 $\left[S(i) - S \right]$
 $\left[S(i) - S \right]$

components of K_{ij}^{α} -tenso Note, that to get relative phase permeability t $\overline{}$ \overline{a} $=$ *l*); but summ $\sum_{i=1}^{n}$ *i* $\sum_{i=1}^{n}$ $\lambda = \int -i\lambda$, i **S** $i = j = j$ $=$ $j = i$); but

 $\frac{1}{\sqrt{2}}$ $\begin{bmatrix} I(t) \end{bmatrix}$ ($\begin{bmatrix} I(t) \end{bmatrix}$ ($\begin{bmatrix} I(t) \end{bmatrix}$) component is obtained by division by one of the main com- $\frac{a_i^2}{b_i^2} = \left(b_i + \left\{ \frac{I_1(k)}{2k} - 1 \right\} \left((S - S(i))^* \right) \right)$ ponents of K_{ij} -tensor. In eg. (9) there's one of the possible therefore fourth phase permeasing for a formally $\begin{bmatrix} S_{(i)} - S(U)^{+} \end{bmatrix}$ Therefore relative phase permeability for a nondiagonal $\lceil \frac{r_1(r_1)}{r_2(r_2)} \rceil$ component is obtained by division by one of the main com- $\varphi_i^2 = \left| b_i + \left| \frac{I_1(k)}{3k} - 1 \right| \left(S - S(i) \right) \right|$ for example the solution by division by the state than components of K_{ij} -tensor. In eg. (9) there's one of the possible vision by one of the main components of the possible values o

etry of filtration properties, so they are the n ters experimentally determined; symmetry it's needed to set $k_{13}^{\alpha} = k_{23}^{\alpha} = 0$ in equations (9), to the latter condition. where *αi*, *bi*, *εi*, *βi* are parameters experimentally determined; in which case () () ¹ * ^α*ⁱ* = ^ϕ*ⁱ S ⁱ* , \int_{0}^{β} Equ. (9) determine phase permeability for triclinic symand phase p dianed the obtained three classes) can be obtained thr *i* and phase permeabilities for all anisotropy types (symmetry classes) can be obtained through them. For monoclinic rotation angles permetters in *k* the contraction of the contract *a* symmetry, $k_{13}^{\alpha} = k_{23}^{\alpha} = 0$ in equations (*k*) for orthotropic symmetry, $k_{13}^{\alpha} = k_{23}^{\alpha} = k_{12}^{\alpha} = 0$, for trans ded through versal – isotropic symmetry it's needed to add the equality tric param-
tric param-
 $k_{11} = k_{22}$ to the latter condition r gas (8) metry of filtration properties, so they are the most general, and phase permeabilities for all anisotropy types (symmetry classe classes) can be obtained through them. For monoclinic *k* $s(i)*$). For orthotropic symmetry, $k_{13}^{\alpha} = k_{23}^{\alpha} = k_{12}^{\alpha} = 0$, for trans*k* B_1 and B_2 reduce to the permeability tensors B_1 neters experimentally determined; symmetry it's needed to set $k_{13}^{\alpha} = k_{23}^{\alpha} = 0$ in equations (9), rot orthonolopic symmetry, $\kappa_{13}^2 - \kappa_{23}^2 - \kappa_{12}^2 = 0$, to trans-23 41 1 42 2 43 3 $\left| \frac{1}{x} \right|$ – for on or gas (8) metry of filtration properties, so they are the most general, *k*_Qu. (9) determine phase pern and phase permeabilities for all anisotropy types (symmetry Equ. (9) determine phase permeability for triclinic symich case $\alpha_i = \varphi_i^1(S_{(i)}^*)$, $b_i = \varphi_i^2(S(i)^*)$. for orthotropic symmetry, $k_{13}^{\alpha} = k_{23}^{\alpha} = k_{12}^{\alpha} = 0$, for transabsolute permeability tensor. – isotropic symmetry it's needed to add the equality *k*11 = *k*22 to the latter condition. versal – isotropic symmetry it's needed to add the equality Using relationship (4) it can be shown, that tensors ^α *Kij* and *Kij* can belong to different to the latter condition.**The analysis of the main axes of phase permeabilities tensor on saturate permeabilities tensor on saturate permeabilities tensor on saturate permeabilities tensor on saturate permeabilities of phase permeabilities of phas** vision by one of the mass permeasurity for the main components of the main components of the post-
 $\begin{pmatrix} 8 \end{pmatrix}$ the position of the posit $\left|\frac{S(i) - S}{i}\right|$ = for oil or gas (8) Equ. (2) determine phase permeability for

The analysis of the dependence of the main axes of phase permeabilities tensor on saturation fixed, then in equation (11) the tensor component values depend on saturation and change; 111 **221 232 232 232 242 242 242 24** ² ¹² ² ence of the main axes of phase permeabilities ten *k k* e of the main axes of phase permeabilities tensor on saturation To keep our following considerations more visualized, an analysis of the dependence **ration** ependence or the main axes or phase permeabilities tensor on saturation **The analysis of the dependence of the main axes of phase permeabilities tensor on saturation**

To keep our following considerations more visualized, α *k* an analysis of the dependence of the main axes on saturation analysis of the dependence of the main axes on saturation for tensors with monoclinic symmetry of filtration proper-
filtration properties the position of one main ax ties is done. It's well known, that any symmetric tensor of So, reducing the main axes is realized by rota turn the coordinate system at angles *φα k* alysis of the dependence of the main axes on saturation for the main axes, in which monoclinic symmetry of the main axes on saturation a diagonal form. In particular, for monoclinic s α alysis of the dependence of the main axes on saturation α a diagonal form, in particular, for monochine.

 $2nd$ rank can be reduced to the main axes, in which it takes a diagonal form. In particular, for monoclinic symmetry of nic symmetry of filtration proper-
filtration properties the position of one main axis is known. ymmetric tensor of So, reducing the main axes is realized by rotation around phase and relative phase permeability values in anisotropic media are dependent on direction, However, if in equation (10) all the component values are constant and angle *φ* is is more visualized, \mathbb{Z}^m rank can be reduced to the main axes, in which it takes $m = \frac{1}{2}$ measures. In the relative phase permeability function of the relative phase permeability functions in the relative parameter $\frac{1}{2}$ he reduced to the main avec in which it takes fixed, the tensor component values, the tensor component values depend on saturation and changes $\frac{1}{2}$ I form. In particular, for monoclinic symmetry of However, in the component values are position of one main and is known. wn, that any symmetric tensor of So, reducing the main axes is realized by rotation around axes, in which it takes a diagonal form. In particular, $\frac{1}{2}$ $\frac{1}{2}$ or following considerations more visualized, $\frac{1}{2}$ nd rank can be reduced to the main avec in which it takes $\frac{1}{2}$ considerations more visuanzed, $\frac{2}{10}$ rank can be reduced to the main axes, in which it takes a diagonal form. In particular, for monoclinic symmetry of α and α filtration α filtration α filtration α

that principle axis. Assuming that a principle axis consides with axis *Z*, then a rotation angle is defined by rotation angle is defined by where summation with respect to (*i*) is absent.

tg
$$
2\varphi = \frac{2k_{12}}{k_{11} - k_{22}}
$$
 (10) To illustrate the effect of dependence of the position of the main axes on saturation let's assume, that $k_1: k_2: k_3$

By analogy reducing the phase permeability tensors $= 4:2:1$ and take basi K_{ij}^{α} to the main axes it's needed to turn the coordinate (9) as equal: system at angles φ^{α} , so: ² ¹² ² *tg* $\frac{1}{2}$ = K_{ij}^{α} to the main axes it's needed to turn the coordinate *k k* $\frac{1}{2}$ ducing the phase permeab $\frac{1}{2}$ as equal. θ , so.

$$
tg\ 2\varphi^{\alpha} = \frac{2k_{12}^{\alpha}}{k_{11}^{\alpha} - k_{22}^{\alpha}}
$$
 for oil:
\n
$$
\epsilon_{11} = 1,4; \ \epsilon_{22} = 2; \ \epsilon_{12} = 1,8; \ \epsilon_{11} = 1,4; \ \epsilon_{22} = 2; \ \epsilon_{12} = 1,8; \ \epsilon_{11} = 1,4; \ \epsilon_{21} = 2; \ \epsilon_{12} = 1,8; \ \epsilon_{22} = 2; \ \epsilon_{23} = 1,8; \ \epsilon_{31} = 1,4; \ \epsilon_{42} = 1,4; \ \epsilon_{53} = 1,4; \ \epsilon_{64} = 1,4; \ \epsilon_{75} = 1,7; \ \epsilon_{86} = 1,8; \ \epsilon_{19} = 1,14; \ \epsilon_{10} = 1,14; \ \epsilon_{11} = 2,14; \ \epsilon_{12} = 2,14; \ \epsilon_{13} = 2,14; \ \epsilon_{14} = 2,14; \ \epsilon_{15} = 2,14; \ \epsilon_{16} = 2,14; \ \epsilon_{17} = 2,14; \ \epsilon_{18} = 2,14; \ \epsilon_{19} = 2,14; \ \epsilon_{10} = 2,14; \ \epsilon_{11} = 2,14; \ \epsilon_{12} = 2,14; \ \epsilon_{13} = 2,14; \ \epsilon_{14} = 2,14; \ \epsilon_{15} = 2,14; \ \epsilon_{16} = 2,14; \ \epsilon_{17} = 2,14; \ \epsilon_{18} = 2,14; \ \epsilon_{19} = 2,14; \ \epsilon_{10} = 2,14; \ \epsilon_{11} = 2,14; \ \epsilon_{12} = 2,14; \ \epsilon_{13} = 2,14; \ \epsilon_{14} = 2,14; \ \epsilon_{15} = 2,14; \ \epsilon_{16} = 2,14; \ \epsilon_{17} = 2,14; \ \epsilon_{18} = 2,14; \ \epsilon_{19} = 2,14; \ \epsilon_{10} = 2,14; \ \epsilon_{11} = 2,14; \ \epsilon_{12} = 2,14; \ \epsilon_{13} = 2,14
$$

therefore (10) all the angles However, if in equation (10) all the component values for water: are constant and angle φ is fixed, then in equation (11) $\beta_{11} = 2$; $\beta_{22} = 2.5$; $\beta_{12} = 2.2$; the tensor component values depend on saturation and
 $S^*_{22} = 0.9; b_{11} = b_{22} = b_{12} = 1$ and relative pha and relative phase permeability values in anisotropic section of the related phase permeability demon 23 41 $\frac{3}{2}$ 41 $\frac{3}{2}$ 41 $\frac{3}{2}$ 41 $\frac{3}{2}$ 41 $\frac{3}{2}$ 41 $\frac{3}{2}$ Indeed, as it was shown in experiment [8], the phase and substituting these values into (11) , we estimate change; thereform α α α α $\frac{1}{2}$ for a state of $\frac{1}{2}$ for $\frac{1}{2}$ for $\frac{1}{2}$ for $\frac{1}{2}$ for $\frac{1}{2}$ and $\frac{1}{2}$ for μ and μ are tensor computed produced phase and relative phase and relative permeability values correspond to higher phase and relative system. tive phase permeability values. In the representation of $k^{\alpha}(n_i) = k$ the relative phase permeability functions it's taken into consideration by determination of the different values
 $2k_{12}^{\alpha} \cos \beta \sin \beta + k_{22}^{\alpha} \sin^2 \beta$ of experimental constants and degrees in equ. (9) for different directions. In fig. 5 the calculation results are shown as the crosschange; therefore the angles φ^{α} values can change also. l (edia are and relative phase permeability values in anisotropic section of the related p
media are dependent on direction, and higher absolute surfaces $k^{\alpha}(n_i) = k_{ij}^{\alpha} n_i n_j$ [−] permeability values correspond to higher phase and rela- $\overline{1}$ lò phase per tive phase permeability values. In the representation of $k^{\alpha}(n_i) = k_{ij}^{\alpha} n_i n_j = k_{11}^{\alpha} \cos^2 \beta +$
the relative phase permeability functions it's taken into However, if in equation (10) all the component values for water: shown in experiment [8], the phase and substituting these values into (11), we estimate a crossdifferent directions. θ also. $\frac{1}{2}$ $\frac{1}{2}$ and substituting these values into $\frac{1}{2}$, we estimate per- \int_0^{∞} for calculation results are shown as the indicators of the indica For the directions. In the discussion of the calculation results are shown as the cross-

Obviously, the angles φ^{α} will not depend on saturation, sections of the indiif in equ. (11) all the parameters, consistory saturation, From the p will be reduced. However it's impossible, because, as it was mentioned above, the experimental constants values in opposite directions is taking place and that's constants values are dependent on direction. Therefore, if the values of the by the experimental results $[8]$. equ. (11) all the parameters, consistory saturation, From the po

Assuming that a principle axis consides constants in (9) are determined, then it's possible to analyze rotation angle is defined by a change in the position of the main axes in two-phase flows **Representation of the properties the properties the main axis is the main axis is reducing to the main axis is reducing to the main axis is red**

> $= 4:2:1$ and take basic parameters for oil and water in (9) as equal: of the main axes on saturation let's assume, that $k_1:k_2:k_3$ grees in equal different differ

, so: for oil:

To keep our following considerations more visualized, an analysis of the dependence

$$
\varepsilon_{11} = 1, 4; \varepsilon_{22} = 2; \varepsilon_{12} = 1, 8; \varepsilon_{11} = 1, 4; \n\mathcal{E}_{11} = 1, 4; \varepsilon_{22} = 2; \varepsilon_{12} = 1, 8; \varepsilon_{11} = 1, 4; \nS_{(11)*} = 0, 1; \alpha_{11} = \alpha_{22} = \alpha_{12} = 1
$$
\nequation (10) all the component values for water:

for water:

equation (11)
\n
$$
\beta_{11} = 2; \beta_{22} = 2,5; \beta_{12} = 2,2;
$$
\n
$$
S^*_{22} = 0,9; b_{11} = b_{22} = b_{12} = 1
$$

section of the related phase permeability demonstrative gher absolute surfaces $k^{\alpha}(n_i) = k_{ij}^{\alpha} n_i n_j$ by the plane XY: 8], the phase and substituting these values into (11), we estimate a cross-

resentation of

\n
$$
k^{\alpha}(n_{i}) = k_{ij}^{\alpha}n_{i}n_{j} = k_{11}^{\alpha}\cos^{2}\beta + k_{12}^{\alpha}\cos^{2}\beta + 2k_{12}^{\alpha}\cos\beta\sin\beta + k_{22}^{\alpha}\sin^{2}\beta
$$
\nFrench values

From the polar diagrams shown it's seen, that with inon saturation, sections of the indicatory surfaces of filtration properties. ed. However it's impossible, because, as it creasing saturation a turn of the main axes of the tensors in opposite directions is taking place and that's confirmed by the experimental results [8].

Fig. 5. Cross-section of the absolute and phase permeability tensor directional surfaces for water (a) and oil (b) under mase permeability tensor uncertonal surfaces for water (a) and on (b) under
 $= 0.2 \cdot 2 = 0.4 \cdot 2 = 0.6 \cdot 4$ shocked permeability saturation values; $1 - s = 0.2$; $2 - s = 0.4$; $3 - s = 0.6$; $4 -$ absolute permeability

 $\mathcal{L}(\mathcal{L})$

k rnn nn D L

l

The method for the laboratory determination of non diagonal component phase permeability tensors [2] 22 **k** . The m r_{eff} equipment enables to calculate a flow in samples to create a set of the neither are neither associate and neither a thinneed and neither an agonal component phase permeability tensors [2] the determination of the component ^α mination of phase and relative phase permeabilities along the main directions of the tensor *kij*, *heta it's construction* the diagonal components ϵ is a component value of ϵ is a construction value of ϵ calculations determination of non-diagrams around can be cut out along the bisectrix of the angles to the $\bf e$ faboratory determination of non-diagonal component phase permeability tensors [2] of them are cut out along two main directions of the tensor *kij* in the *XY*-plane. To make our calculations more conveniently determination or non-diagonal component To determine and a series and a series and a series are a series of the series of the series of the series of **12** *k* it's necessary first to determine the diagonal component of the diagonal components \mathbf{r}

Let's assume, that porous media has monoclinic sym-
 $Q^{\alpha}u^{\alpha}L\left[\overline{k_{n}^{\alpha}n_{n}}\right]$ metry of filtration properties; obviously, in case of tri-
 $\frac{Q(\mu)}{S \cdot \Delta n} \sqrt{\frac{m n!}{\epsilon^n n!}}$ clinic symmetry the considerations would be analogous.
 $S \cdot \Delta p \sqrt{r_{lm}n_l n_m} \sqrt{R_{ij}n_l n_j r_{lm}n_l n_m} + (D/L)$ Further we'll assume, that the position of the known main axis of the absolute permeability tensor coincides with the Z-axis. In this case the non-zero non-diagonal components of the phase permeability tensors are the k_1^{α} com-
 n_i – vector components, setting a direction-Further we'll assume, that the position of the known main where
some of the shealute permeability tensor equalities with Q^{α} is debit of $e^{i\beta}$ phase. An approximate distance I ponents. *p* coments. $Let's $_{\text{ass}}$$ $\frac{m}{\epsilon}$ $\frac{1}{100}$ components of the tensors can be done by conventional methods $\frac{1}{100}$. mination of phase and relative phase permeabilities along the main directions of the tensor *kij*, **12 Purtner we** axis of the ponents $\overline{}$ ζ axis of the absolute permeability *k nn* ¹² *k* can be as follows. For doing it, we'll use two model axis of the absolute permeability tensor coincides with Q^{α} is debit of α^{th} phase, Δp – pressure dro $\frac{1}{2}$ ľ *h h z*-axis. In this case the non-zero not the Z-axis. In this case the non-zero non-diagonal com-
 S is area of sample cross-section, $D -$ sa of the phase permeability tensors are the κ_{12} com-
 n_i – vector components, setting a direction the determination of the component ^α $\frac{1}{2}$ and $\frac{1}{2}$ are defined as the above meaning solution of $\frac{1}{2}$ and $\frac{1}{2}$ are $\frac{1}{2}$ ar ponents of the phase permeability tensors are the k_{12}^{α} com-
non-normal pressure n_i – vector components Let's assume, that porous media has monoclinic sym-
 $Q^{\alpha} \cdot \alpha I$ $\int \rho^{\alpha} \mu^{\alpha} L$ (the tensors components from beginning by conventional methods $\int \rho^{\alpha} \mu^{\alpha} L$ metry of intration properties, obviously, in case of the $\frac{1}{S \cdot \Delta p} \sqrt{\frac{1}{E}}$ \mathbf{p} and \mathbf{p} are \mathbf{p} above mentioned solutions: θ that the negation of the known main where

between two main directions. The determination of phase and relative phase permeabilities

dependence on pressure drop we can use an approximate flows, and this, in To determine k_{12}^{α} it's necessary first to determine the Since the tensor r_{ij}^{α} and k_{ij}^{α} are inter-constant. diagonal components values k_{11}^{α} and k_{22}^{α} . Therefore to per-
we have: form laboratory studies it's necessary to cut out three tions of the tensor k_{ij} in the XY-plane. To make our calcu-

(1 if $i = i$) lations more convenient the third sample can be cut out where δ_{ij} – Kroneker symbol $\delta_{ij} = \begin{cases} 1, & if \quad i = j \end{cases}$ meabilities for diagonal components of the tensors can be as follows. The determination of phase and relative phase done by conventional methods [6]. After termination of known tensors k_{ij}^{α} components $\frac{1}{2}$ is given for different anisotropy types. A new method for complex laboratory studies of anisophase and relative phase permeabilities along the main equation, where the only un directions of the tensor k_{ij} , the determination of the com-
nonent k_{i2}^{α} can be as follows. For doing it we'll use two can be found by fit ponent k_1^{α} can be as follows. For doing it, we'll use permeability value can be defined, and in the second case The generalization of $\frac{1}{2}$ along the bisectrix of the angles quate description of filtration flows, and this, in turn, allows optimization of oil recovery mination of phase and relative phase permeabilities along the main directions of the tensor *kij*, ponent κ_{12} can be as follows. For doing it, we fit model problems: flow through a «thin» plate and move-
mort in a «long» ber [6]. In the first age a directional debit value is obtained model problems. How unough a want, place and move obtained operational metal in a wlong bar [6]. In the first case a directional debit value is obtained by t [1] Collins R. E.: *Flow of fluids through porous materials*. New York: R. P. C. 1961, 348 samples. Two of them are cut out along two main direc-
 $k_{ij}^{\alpha} \cdot r_{il}^{\alpha} = \delta_{ij}$ (13) meabilities for diagonal components of the tensors can be
the Using equ. (12) we calculate tensor r_{ij}^{α} approximate formula based on the above mentioned solutions: - a directional filtration resistance. Laboratory equipment anisotropic fractured-porous media is pre a thin plate, nor a long bar. Therefore to define the debit properties enables more adequate descript lations of the tensor κ_{ij} in the XT plane. To make our calculation
lations more convenient, the third sample can be cut out where δ_{ij} – Kroneker symbol, $\delta_{ij} = \begin{cases} 1, & if & i = j \\ 0, & if & i \neq j \end{cases}$ along the bisectrix of the angle between two main direc-
along the bisectrix of the angle between two main directions. The determination of phase and relative phase perse and relative phase per-
nents of the tensors can be Using equ. (12) we calculate tensor r_{ij}^{α} components by the ponent k_1^{α} can be as follows. For doing it, we'll use two can be found by fitting with enables to create a flow in samples, which are neither Allowance of formula based on the above mentioned solutions: processes. tions of t *dir* components by the known tensors and the known tensors and the known tensors are the known tensors and the known tensors are the $\overline{}$ a thin plate q_{min} p_{max} *i il* $\frac{1}{2}$ *il* $\frac{1}{2}$ $\frac{$ $\frac{11}{11}$ $\frac{1}{\sqrt{2}}$ ⁼ ⁼ *if ⁱ ^j if i j* ,1 ^δ . t_{re} and t_{re} core-samples in the determination of t_{re} filtration properties of t_{re} and t_{re} and t_{re} and t_{re} processes. dependence on pressure drop we can use an approximate flows, and this, in turn, all ϵ for different and the complex method for complex laboratory studies of ϵ complex laboratory studies of anisotions of the tensor k_{ij} in the XY-plane. To make our calcu-Ĩ. $\overline{}$ lations more convenient, the third sample can be cut out where δ_{ij} – Kroneker symbol, $\delta_{ij} = \begin{cases} 1, & if \quad i = j \\ 0, & if \quad i \neq j \end{cases}$ permeability value can be defined, and in the second case The generalization of a model with dual por $\frac{1}{2}$, $\frac{1}{2}$ \int_0^∞ determine k_{12}^α it's necessar *r nn* ^α ^α ^α ^µ 1 $\frac{1}{2}$ $\mathbf n$ ⁼ ⁼ *if ⁱ ^j if i j* ,1 ^δ . Since the tensor ^α *ij r* and ^α enables to create a flow in samples, which are neither Allowance of an + *k rnn nn D L k nn Q L mllmjiij jiij* α α ^α ^α ^α ^µ 1 *ij il ij k r* ^δ ^α ^α ⋅ = (13) ,₁₁₁ , ,
,,,, between the starting the finally dependent, where an interesting that k_{12}^{α} .

For doing it, we'll use two can be found by find a «thin» plate and move-

 (D/L) (D/L) i. $\overline{}$ $\overline{}$ L $\overline{}$ L \mathbf{r} + + \cdot Δp $\left| \right. \left| \right$ $k_{ii}^\alpha n_i n_j r_{lm}^\alpha n_l n_m (D/L)$ $r_{lm}^{\alpha}n_l$ n $k_{ii}^{\alpha} n_i n$ $S \cdot \Delta p$ $Q^{\alpha} \mu^{\alpha} L$ η ^{*ii*} μ _{*iii* η ^{*i*} μ </sup> η} η *ij* μ _i μ _j μ _{lm} μ _{l μ </sup>m} *mllm* $\frac{\alpha}{\alpha} \left| \frac{1 + \kappa_{ij} n_i}{1 - \alpha} \right|$ α α α $\left\{ \alpha \mu^{\alpha} L \quad \left| k_{ij}^{\alpha} n_i n_j \right| 1 + k_{ij}^{\alpha} n_i n_j n_{lm}^{\alpha} n_l n_m (D/L) \right\}$ (12) plate, nor a long bar. Therefore to define the debit dependence on pressure drop we can use an $\left\{ \frac{d}{d n_i n_j r_{lm}^{\alpha} n_l n_m + \left(D/L \right) \right\}$ *k rnn nn D L* $\sqrt{\frac{1}{n} \left[1 + k^{\alpha} n n \right] \mu^{\alpha} n}$ $\frac{\mu_j}{\mu} \left| \frac{1 + \kappa_{ij} \mu_i \mu_j \mu_{lm} \mu_l \mu_m (D/D)}{I} \right|$ (12) n_m | $k_{ij}^{\alpha} n_i n_j r_{lm}^{\alpha} n_l n_m$ + (D/L) | α_{μ} α_{ν} α_{μ} α_{μ} α_{μ} α_{μ} α_{μ} α_{μ} α_{μ} α_{μ} $\frac{Q}{\mu}$ $\frac{\mu}{\mu}$ $\frac{N_{ij}n_i n_j}{\mu}$ $\frac{1 + N_{ij}n_i n_j n_{ij} n_m (D/L)}{\mu}$ (12) $S\cdot \Delta p \parallel r_{lm}^{\alpha}n_l n_m \parallel k_{ij}^{\alpha}n_l n_j r_{lm}^{\alpha}n_l n_m + (D/L) \parallel$ resistance. Laboratory equipment enables to create a flow in samples, which are neither a thin 12 *k* $\frac{Q}{a}$ if $\frac{N_{ij}}{a}$ is necessary first to determine the diagonal contribution of the diagonal components $\frac{Q}{a}$ is $\frac{N_{ij}}{a}$ if $\frac{N_{ij}}{a}$ is $\frac{N_{ij}}{a}$ if $\frac{N_{ij}}{a}$ is $\frac{N_{ij}}{a}$ if $\frac{N_{ij}}{a$ $\sqrt{2\pi}$ $\sqrt{2\pi}$. Therefore to cut out the samples in the same studies in the same studies in the same studies. $\left| \frac{\kappa_{ij} n_i n_j}{\sigma_i} \right|$ $\frac{1 + \kappa_{ij} n_i n_j r_{lm} n_l n_m (D/L)}{\sigma_i}$ (12) $\int r_{lm}^{\alpha} n_l n_m \int k_{ij}^{\alpha} n_i n_j r_{lm}^{\alpha} n_l n_m + (D/L)$ between two main directions. The determination of phase and relative phase permeabilities for diagonal components of the tensors can be done by conventional methods [6]. After termous meana has monocumic sym-
 $O^{\alpha} \mu^{\alpha} L \left[k_n^{\alpha} n_i n_i \right] 1 + k_n^{\alpha} n_i n_i r_m^{\alpha} n_i n_m (D/L)$ $\overline{S \cdot \Delta p} \sqrt{\overline{r_{\mu}^{\alpha} n_{\mu} n_{\mu}}} \sqrt{\overline{k_{\mu}^{\alpha} n_{\mu} n_{\mu} n_{\mu} + (D/L)}$ (12) as media has monoclinic sym-
 $Q^{\alpha} u^{\alpha} I = \sqrt{k^{\alpha} n n} \left[1 + k^{\alpha} n n r^{\alpha} n n \left(\frac{D}{I}\right)\right]$ operties; obviously, in case of tri-
 $\frac{Q(\mu + E)}{R} \left[\frac{(\mu + E)}{R} \frac{(\mu + E)}{(\mu + E)} \frac{(\mu + E)}{(\mu + E)} \frac{(\mu + E)}{(\mu + E)} \right]$ (12

where ρ is a long barrefore to define the define the define the define the dependence on pressure drop we can use an use and use an use and use an use and use an use and use an

where
 Q^{α} is debit of α^{th} phase, Δp – pressure drop at distance L, S is decreased by $\sum_{i=1}^{n} P_i$ pressure drop at distance D_i ,
S is area of sample cross-section, D – sample diameter, n_i – vector components, setting a direction of symmetry ponents. axis of core, r_{ij}^{α} -tensor of filtration resistance. $\overline{}$ $\frac{1}{2}$ ermeability tensor coincides with Q^{α} is debit of α^{th} phase, Δp – pressure drop at distance L, the non-zero non-diagonal com-
S is area of sample cross-section, D – sample diameter, onems, setting a direction \overline{a} ermeability tensors are the k_{12}^{α} com-
 n_i – vector components, setting a direction of symmetry neter, $\frac{1}{2}$ axis of core, r_{ij}^{α} tensor of filtration resistance. ermeability tensor coincides with Q^r is debit of a^r phase, Δp – pressure drop at distance L

12 **k** it the tensor r_i^{α} and k_i^{α} are inter-convertible, then where *δij* – Kroneker symbol, Since the tensor r_{ij}^{α} and k_{ij}^{α} are inter-convertible, then
we have: we have: ensor r^{α} and k^{α} are inter-convertible, then since the defermine the definition of the debit dependence on r_{ij}^{α} and k_{ij}^{α} are inter-convertible, then

$$
k_{ij}^{\alpha} \cdot r_{il}^{\alpha} = \delta_{ij}
$$
 (13)
-
where δ_{ij} - Kroneker symbol, $\delta_{ij} = \begin{cases} 1, & if i = j \\ 0, & if i \neq j \end{cases}$

¹² *k* can be as follows. For doing it, we'll use two model

For the termination of the create a flow in sample $\sum_{i=1}^{\infty}$ can be calculated the thin $\sum_{i=1}^{\infty}$ is presented in ref. [3]. We get an eabilities along the main equation, where the only unknown value is a component k_{12}^{α} . eabilities along the main equation, where the only unknown value is a component k_{12} .

determination of the com-

Assuming that k_{12}^{α} lies between 0 and 1, the component value

are doing it, we'll use two some be e found ween experimental and theoretical debit value. Theo wo can be found by fitting with minimization of the difference first case a directional debit value is obtained by the calculation of component k_{12}^{α} . K_{ij} components. Then hom (15) we get an and is confirmed by the calculation of component κ_{12} . known tensors k_{ij}^{α} components. Then from (13) we get an means $\lim_{\alpha \to 0} \frac{1}{\alpha}$ ref. α . allows a component κ_{12} . [6]. In the first case a directional debit value is obtained by the calculation of component k_1^{α} . be permeabilities along the main equation, where the only unknown value is a component k_{12}^{α} . $A = \frac{1}{2}$ of $\frac{1}{2}$ of $\frac{1}{2}$ of $\frac{1}{2}$ of $\frac{1}{2}$ or $\frac{1}{2}$ o $\frac{1}{2}$ between experimental and theoretical debit value. Theoretical ب
, hows. For doing it, we'll use two can be found by fitting with minimization of the difference *using equilibrium tensors από το προσπέθηση του προσπέθ* be Using equ. (12) we calculate ten

ed, and in the second case The generalization of a model with dual porosity on opic fractured-porous media is presented in ref. $[3]$. in the second case The generalization of a model with dual porosity on $\frac{1}{2}$ is confirmed by experiments. General representation of the component RFP tensors $\frac{1}{2}$ tensors $\frac{$ n resistance. Laboratory equipment anisotropic fractured-porous media is presented in ref. [3].

 μ anset optimization person means is presented in terms of μ . *i*₀, *i*^{*l*} *il***₁, i**^{*l*}₁ \boldsymbol{S} $\ddot{}$ $\frac{1}{2}$ $\frac{1}{2}$ **processes**. herefore to define the debit properties enables more adequate description of filtration recovery process more adequate description of initiation
and this, in turn, allows optimization of oil recovery formula based on the above mentioned solutions: processes. of oil-gas recovery processes. hows, and this, in turn, allows optimization of oil recovery x in samples, which are neither Allowance of anisotropy of the reservoir and filtration t porous media. For two-phase flows, the analysis of new effects due to anisotropy is given. flows, and this, in turn, allows optimization of oil recovery $\frac{1}{\sqrt{1-\frac{1$

Using equ. (12) we calculate tensor ^α This knowledge enables more adequate simulation of filtration flows and allow optimization **Conclusion** ion recovery processes. \mathcal{A} and filtration properties enables more adequates more adequates \mathcal{A} α conclusion α t^2 conclusion of filtration of filtration properties of anisotropic properties of anisot cally and is confirmed by experiments. General representation of the component \mathcal{L}_p tensors \mathcal{L}_p tensor i s given for different anisotropy types. A new method for conclusion i

1 interest also that and relative phase abilities (KFP) is shown incordinately experiments. General representation simulation simulation and the experiments of the α for complex laboratory studies of anisotropic core-samples allow optimization of oil-gas recovery pre $i₁$ is given anisotropy types. A new method for complex laboratory studies of aniso-to-planets $\frac{1}{2}$ abilities (RF abilities (RFP) is shown theoretically and is confirmed by anisotropic porous fluids $\left(\mathbf{R} \cdot \mathbf{r}\right)$ is shown incordidatily and is committed by a anisotropic porous means. experiments. General representation of the component RFP of new effects due to anisotropy is given. processes. tropic core-samples is suggested for the determination of filtration properties of anisotropic tensors is given for different anisotropy types. A new method enables more adequate simulation of filtr for complex laboratory studies of anisotropic core-samples allow optimization of oil-gas recovery pro Tensor nature of absolute and relative phase perme-
is suggested for the

Bibliography $T_{\rm tot}$ more adequate simulation of filtration flows and allow optimization α or α **Bibliography**

- **Conclusion** 9 **Bibliography** p. New York: R. P. C. 1961, 348 p. [1] Collins R. E.: *Flow of fluids through porous materials*.
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It can be adia. Doclady Physics. [6] Dmitriev N. M.: On the method of permeability deter-

EXECUTE: IS suggested for the determination of filtration properties of ically and is confirmed by anisotropic porous media. For two-phase flows, the analysis tion of the component RFP of new effects due to anisotropy is given. This knowledge erent anisotropy types. A new method enables more adequate simulation of filtration flows and studies of anisotropic core-samples allow optimization of oil-gas recovery processes. solute and relative phase perme-
is suggested for the determination of filtration properties of [1] Collins R. E.: *Flow of fluids through porous materials*. New York: R. P. C. 1961, 348 p. $\frac{d}{dx}$ and $\frac{d}{dx}$ representation of the component Proposition of the component RFP tensors $\frac{d}{dx}$ σ different and two-phase hows, the analysis of oil-gas recovery processes. In theoretically and is confirmed by anisotropic porous media. For two-phase flows, the analysis $\frac{1}{100}$ is given for different and $\frac{1}{100}$ of a new effects due to constraint is given. This imagination t^2 core-septes is such an isotropy is given. This knowledge of new effects due to anisotropy is given. This knowledge

- T_{total} of a model and relative persons meads. $\frac{1}{2}$. The process meads. $\frac{1}{2}$. w of fluids through porous materials. [4] Dmitriev N. M., Maksimov V. M.: Non-linear lows of p. *fluid flow through anisotropic porous media*. J. Appl.
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ZAKŁAD OCENY WŁAŚCIWOŚCI EKSPLOATACYJNYCH

Zakres badania:

- badania właściwości użytkowych paliw silnikowych w testach stanowiskowych (LO, LC, Mercedes M102 i M111, Peugeot XUD9);
- oznaczanie stabilności oksydacyjnej biopaliw (test Rancimat);
- ocena właściwości użytkowych paliw i olejów smarowych w badaniach eksploatacyjnych;
- ocena wybranych, fizykochemicznych właściwości użytkowych paliw i środków smarowych (oddziaływanie na metale i elastomery, odporność na działanie wody, odporność na utlenianie, skłonność do pienienia, stabilność podczas przechowywania);
- ocena właściwości smarnych olejów napędowych (test HFRR) oraz środków smarowych i cieczy hydraulicznych;
- oznaczanie zanieczyszczeń paliw i środków smarowych;
- oznaczenia właściwości reologicznych olejów w szerokim zakresie temperatur (testy CCS, HTHS, MRV, Brookfield);
- ocena kompatybilności dodatków do paliw i olejów smarowych;
- ocena stopnia degradacji olejów smarowych w badaniach stanowiskowych i podczas eksploatacji u użytkownika;
- badania pasywnej regeneracji filtrów cząstek stałych na stanowisku z silnikiem o zapłonie samoczynnym.

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