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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

DEVELOPMENT AND APPLICATION OF A METHOD FOR DETERMINING HYDRODYNAMIC CONNECTION BETWEEN FIELDS OBJECTS BASED ON GEOCHEMICAL ANALYSIS OF OIL AND GAS

Specialty: 2525.01 – “Oil and gas field development and operation”

Field of science: Technical sciences

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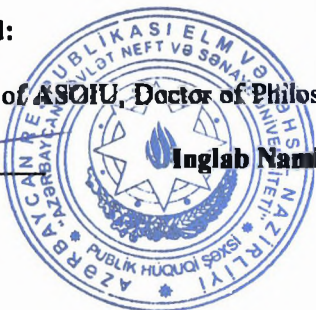
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GENERAL DESCRIPTION OF WORK

Relevance of the topic and degree of development

The results of hydrodynamic modeling of oil and gas, which depend on the correct determination of the hydrodynamic connection between different pay zones, are used to estimate hydrocarbon reserves in fields and also to forecast promising hydrocarbon deposits. The traditional methods used require a lot of financial and time costs and provide less reliable information given the complexity of the approaches used, although most of them were limited to identifying the hydrodynamic connection only between injection and production wells.

In this regard, currently one of the main tasks of the oil industry is the development of effective methods for determining the hydrodynamic connection between different productive pay zones based on the chemical composition and genetic parameters of oil and gas, since with the advent of modern technology and scientific approaches, the need to study their compositions grows at the molecular level.

Also, the correct calculation of the contribution of each layer or deposit to the total production of wells that simultaneously penetrate several productive layers is one of the important issues, since recently most subsoil users have been using jointly operating wells. Therefore, the development of a method for distributing production from jointly producing wells allows us to solve not only this issue, but also the tasks of assessing the efficiency of wells with simultaneous separate operation, the tightness of the packer between their pumps and the vertical isolation of the formations.

Thus, the development and application of methods for determining the hydrodynamic connection between objects based on geochemical analysis of oil and gas is a pressing task.

Object and Subject of Research

The object of the research consists of 1,700 oil samples and 80 gas samples from 120 oil and gas fields of the Republic of Kazakhstan. All studied oil and gas samples were obtained from

various oil, condensate, and gas accumulation zones, as well as different stratigraphic horizons.

Purpose and objectives of the study

The purpose of the study is development and application of methods for determining hydrodynamic connections between objects based on geochemical analyzes of oil and gas

Main objectives of the study:

1. Development of methods for determining the hydrodynamic connection of separately operated objects;
2. Development of methods for distributing hydrocarbon production and assessing the efficiency of operation of jointly developed facilities;
3. Creation of geochemical atlases of oil and associated gas fields of the Republic of Kazakhstan;
4. Development of methods for assessing the quality of oil and petroleum products.

Research methods

The assigned tasks were solved by applying theoretical, experimental and field research methods.

Main provisions submitted for defense

The following are submitted for defense:

1. Methods for determining the hydrodynamic connection of separately operated objects;
2. Methods for distributing hydrocarbon production and assessing the efficiency of operation of jointly developed facilities;
3. Geochemical atlases of oil and associated gas fields of the Republic of Kazakhstan;
4. Methods for determining the quality of oil and petroleum products.

Scientific novelty of the research

1. Methods have been developed for determining the hydrodynamic connection of separately operated objects;
2. Methods for distributing hydrocarbon production and assessing the efficiency of operation of jointly developed facilities are proposed;

3. Geochemical atlases of oil and associated gas fields of the Republic of Kazakhstan were created;

4. Methods have been developed for determining the quality of oil and petroleum products.

Theoretical and practical significance of the results of the work

The methods developed in the work were put into practice to create geochemical atlases of oil and gas based on the analysis of 1700 samples of oil and gas condensate and 80 samples of associated gas from 120 oil and gas fields of the Republic of Kazakhstan. Geochemical atlases were built for seven oil and gas basins of the Republic of Kazakhstan:

1. Southern part of the Caspian basin;
2. Eastern part of the Caspian basin;
3. Northern part of the Caspian basin
4. Ustryurt-Buzachinsky basin.
5. South Mangyshlak basin;
6. South Turgay basin;
7. Shu-Sarysu basin;

Acts on the implementation of methods in the fields are attached to the dissertation.

A patent of the Republic of Kazakhstan No. 7172 dated June 3, 2022 was received for a method for determining the quality of oil and petroleum products.

Approbation of work

The main provisions and results of the dissertation research were reported and discussed at the following scientific conferences:

1. Scientific and Practical Conference "Ecology and the Oil & Gas Complex", NJSC Atyrau Oil and Gas University, Atyrau, 2018.

2. 29th International Meeting on Organic Geochemistry (IMOG 2019) organized by the European Association of Organic Geochemists (EAOG), Gothenburg, Sweden, September 1–6, 2019.

3. Scientific and Practical Conference "Status and Prospects for the Exploitation of Mature Fields", Aktau, May 16–17, 2019.

4. Scientific and Practical Conference "Modern Methods of Field Development with Hard-to-Recover Reserves and

Unconventional Reservoirs", Atyrau, September 5–6, 2019.

5. International Forum "5th KDR Well Engineering Forum", Astana, September 12, 2019.

6. SPE Annual Caspian Technical Conference 2020, presentation on "Integration of Biomarker Analysis with Stable Carbon Isotope Data for Genetic Classification and Hydrocarbon Migration Pathway Tracking in the Precaspian Basin" (Paper ID: SPE-202514-MS), Astana, October 21–22, 2020.

7. SPE Annual Caspian Technical Conference 2021, presentation on "Application of Oil Biomarkers and Fingerprinting for Decoding Genetic Affinity and Predicting Migration Pathways in the Aryskum Trough of the South Turgay Basin" (Paper ID: SPE-207037-MS), Baku, October 5–7, 2021.

8. International Conference "Round Table: Youth and Innovation – the Future of the Oil and Gas Industry" (AtyrauGeo-2021), October 29, 2021.

9. International Conference "Current Issues of Hydrocarbon Resource and Reserve Growth", Satbayev University (KazNRTU), Almaty, May 17–20, 2022. (Awarded 1st Place among presenters).

10. SPE Annual Caspian Technical Conference 2022, presentation on "Geochemical Atlas of Oil and Source Rocks and Oil-Source Rock Correlation: Case Study of Oil and Gas Fields in the Mangyshlak Basin (Kazakhstan)" (Paper ID: SPE-212078), Astana (Nur-Sultan), Kazakhstan, 2022.

11. SPE Annual Caspian Technical Conference 2023, presentation on "Application of Oil Fingerprinting and Biomarker Analysis for Reservoir Connectivity Studies and Genetic Typing of Oils in the North Ustyurt Region" (Paper ID: SPE-217633), Baku, November 23–25, 2023.

12. SPE Annual Caspian Technical Conference 2024, presentation on "Application of Oil Fingerprinting and Biomarker Analysis for Reservoir Continuity and Compartmentalization Studies and Genetic Typing of Oils Derived from Eastern Part of Precaspian Basin (Kazakhstan)" (Paper ID: SPE-223407-MS), Atyrau, November 26–28, 2024.

13. 75th Annual Meeting of the GSA Rocky Mountain Section

(2025), presentation on "Geochemical Characterization and Mineral Composition of Devonian and Mississippian Carbonates, Sacramento Mountains, New Mexico", Salt Lake City, Utah, USA, May 20, 2025.

14. International Scientific and Practical Conference "Geoscience & Exploration Central Asia: Geology, Resources and the Future of Eurasia", presentation on "12 Years of Innovation: Digital Geochemical Atlas of Crude Oils and Gas Condensates of the Republic of Kazakhstan", Astana, April 2–3, 2026.

15. 6th International Scientific and Practical Geological Conference "AtyrauGeo-2026", presentation on "Geochemical Atlas of Oil and Gas Condensates in the Northern Part of the Precaspian Basin and Its Application for Hydrocarbon Potential Forecasting in Paleozoic Deposits", Atyrau, April 23–24, 2026.

16. Conference "Evolution of Geological Exploration in the Republic of Kazakhstan: Innovations and Prospects", presentation on "Geochemical Atlas of Oils in the South Turgay Basin and Its Application for Prospecting Prospective Areas", South-Oil, Shymkent, Kazakhstan, May 21–23, 2025.

Publications

Based on the dissertation materials, 41 scientific papers have been published, of which 24 articles, 16 conference proceedings and 1 patent of the Republic of Kazakhstan for an invention. 14 articles have been published in journals indexed in the Scopus database, 5 articles in journals indexed simultaneously in the Scopus and Web of Science databases, and 7 papers have been presented in conference proceedings indexed in Scopus.

Name of the institution where the dissertation work was completed.

The dissertation work was carried out at the Scientific Research and Design Institute "Neftegaz" of the State Oil Company of the Azerbaijan Republic (SOCAR).

Structure and scope of work

The dissertation work consists of an introduction, three chapters, conclusions, a list of references, and two appendices. The work includes 231 figures, 8 tables, a list of references comprising

122 items, and 6 appendices. The dissertation contains the following number of characters: introduction — 8099; Chapter I — 33389; Chapter II — 47834; Chapter III — 110577; conclusions — 4033. The total number of characters is 203932.

SUMMARY OF THE WORK

The introduction substantiates the relevance of the dissertation work, formulates the purpose, main objectives of the research, scientific novelty and indicates its practical value.

The first chapter of the dissertation presents a literature review of methods for determining hydrodynamic connectivity between separately exploited objects^{1,2}, production allocation for commingled production objects, as well as methods for assessing the quality of oil and petroleum products.

The first section presents the application of seven existing methods for determining hydrodynamic connectivity between objects: tracer testing using Nuraly as an example, pulse-code interference testing and formation water analysis using the Kozhasay field as an example, PVT oil property analysis using Eastern Uaz and Northern Uaz as examples, well logging (geophysical well research), seismic surveying, and traditional geochemical research, along with detailed descriptions of their advantages and disadvantages.

In this case, by the mass of extracted tracers or indicators, it is possible to determine the presence of a hydrodynamic connection between injection and production wells, while the essence of pulse-code hydraulic testing is the response of the production well to the code disturbance of the injection well, which indicates the presence of a hydrodynamic connection between them. Comparison of the ionic composition of formation water from a production well with water from an injection well and cluster pumping stations (BCPS) also makes it possible to determine the hydrodynamic relationship, while as a method for analyzing the PVT properties of oil, a graph of the dependence of gas content on the saturation pressure of formation oil is used to determine hydrodynamic connection between layers.

¹ Кричевский, В.М., Фарахова Р.Р. Отчет по данным исследования методом Импульсно-Кодового Гидропрослушивания (ИКГ) скважины К-105. SofOil, Казахстан, 2019.

² Юньфэй Ц. Гайдамак Е.В., Верба А.Ф. Проведение трассерных исследований на скважинах №201 и №327 месторождения Алибекмола, ТОО СП «Ойл Сمارт Технолоджис, Казахстан, 2018

Well geophysical surveying (GIS) can be used to determine the vertical discontinuity of a reservoir³.

The seismic profile can identify high amplitude areas (bright spots)⁴, which indicate hydrocarbon deposits, although the seismic data attributes can identify a series of faults between the detected deposits and, based on this, make a prediction about the isolation or connectivity of the reservoir, although others are required for confirmation research.

For this purpose, the seismic monitoring method (4D seismic / time-lapse seismic) can also be utilized. The essence of this method lies in comparing a series of 3D seismic surveys conducted over the same area in different years. Changes in pressure, temperature, and rock saturation (the replacement of oil or gas with water) alter the elastic properties of the formation, specifically the velocities of P- and S-waves and the amplitude of the reflected signal. If fluid extraction in one reservoir results in a synchronous change in elastic parameters (acoustic impedance) within an adjacent, seemingly isolated block as recorded on the 4D model, this proves the existence of hydrodynamic communication between them (for example, via a permeable fault or a unified fracture system).

This section also contains references to the results presented in the third chapter, which provides a comparative analysis of the author-developed fingerprinting methodology and the aforementioned traditional research methods.

In the second paragraph, a comprehensive field geophysical study of development control was presented as the only method for distributing oil production of jointly operated facilities⁵, since the analysis of different-speed flow metering measurements together

³ Sazli, N. H. A. Identifying reservoir compartmentalization using field data – Field X case study: Final Year Project— Universiti Teknologi PETRONAS, 2012.

⁴ Ajisafe, Y.C., Ako, B. D. 3-D Seismic Attributes for Reservoir Characterization of “Y” Field Niger Delta, Journal of Applied Geology and Geophysics (IOSR-JAGG) Nigeria., -2013, -p. Volume 1, Issue 2, 23-31 p.

⁵ Курилив С.Т. Головатая О.Н., Заключение по комплексу промыслово-геофизических исследований контроля за разработкой. Геомунайресурс, Казахстан, стр. 1-19 стр. 2014

with moisture metering measurements, inflow indicator and density curve, make it possible to determine inflow intervals and their percentage contribution into the total flow rate of the well and the composition of the incoming fluid.

The third paragraph describes existing methods for assessing the quality of oil and petroleum products. For crude oil, quality indicators are density, sulfur content and fractional composition, while the quality characteristics of commercial oil are the water content in the oil, mechanical impurities and the content of chloride salts, paraffin, pour point and saturated vapor pressure. Indicators of the quality of gasoline are their grades (AI-92, AI-95 and AI-98) and their octane numbers, which indicate the detonation resistance of the fuel.

It is shown that existing methods turned out to be insufficiently effective and the use of geochemical research is an urgent task to determine the hydrodynamic connection between layers and the quantitative distribution of hydrocarbon production of jointly operated objects.

The second chapter presents developed methods for determining the hydrodynamic connection of separately operated facilities, distribution of production and assessment of the operating efficiency of jointly developed facilities, assessment of the quality of oil and petroleum products.

The first paragraph presents developed methods for determining the hydrodynamic connection using geochemical analysis of oil and gas, which are implemented based on the algorithm described below:

i) Oil is selected from wells between which it is planned to determine the hydrodynamic connection.

ii) All delivered oil samples were subjected to centrifugation to separate oil from water (time - 20 minutes, speed - 1000 rpm, temperature - 20C).

iii) Oil and gas analyzes are carried out to determine the component and isotopic composition of hydrocarbons.

iv) Determination of aromatic components at the molecular level for the component composition of oil and gas condensates was

studied on a gas chromatograph with a flame ionization detector, while fingerprinting and biomarker analysis of oil and gas condensates was performed on a multidimensional gas chromatograph with two flame ionization detectors and a gas chromatograph-mass spectrometry in SIM mode (Fig. 1).

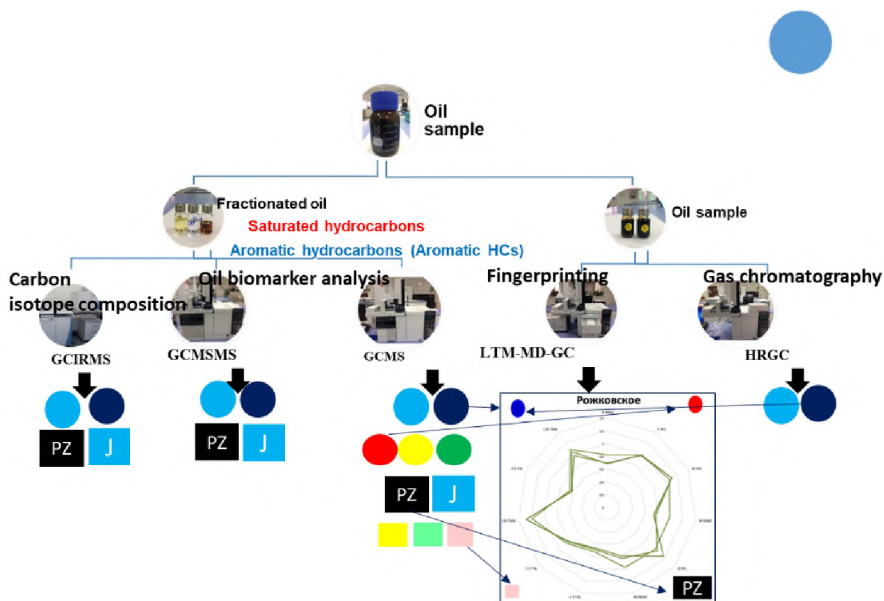


Figure 1 – Applied tools for creating petroleum geochemical atlases

Based on the results of low thermal chromatography (LTM-GC), 11 aromatic components are determined such as ethylbenzene, para-xelol, meta-xelol, isopropylbenzene, ortho-xelol, n-propyl benzene, 4-ethylbenzene, 3-ethylbenzene, 1,3,5 -trimethylbenzene, 2-ethylbenzene, 1,2,4-trimethylbenzene (Fig. 2).

v) Based on the normalization of the aromatic components of oil and the isotopic composition of the carbon of associated gases, star diagrams are constructed for each sample.

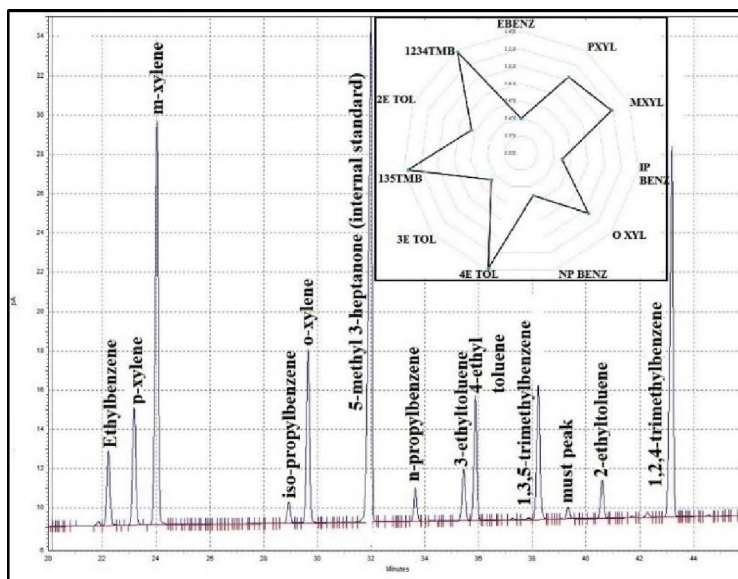


Figure 2 – Identification of 11 aromatic components in oils

Integration of 11 aromatic peaks is carried out on the oil chromatogram, and 7 peaks of the carbon isotope composition are determined on the chromatogram of associated gases.

To construct star diagrams of oil and associated gas, it is necessary to normalize the peaks of the resulting components. Normalization is carried out in the following sequence: a) the sum of the values of 11 peaks is determined; b) the asymptotic value of each peak is determined by dividing by the sum of the values of 11 peaks; c) determination of the average asymptotic value of the peaks; d) normalization, dividing the asymptotic values of the peaks by the average asymptotic value.

vi) Based on a comparison of star diagrams, a conclusion is made about the presence or absence of a hydrodynamic connection between objects.

The conclusion is based on the fact that if oil or gas samples have similar star diagram configurations, then there is a good hydrodynamic connection between the reservoirs of these wells. If

oil or gas samples have different diagrams, then there is a barrier or fault between them that prevents the mixing of fluids.

The second paragraph proposes methods for distributing oil production and assessing the operating efficiency of jointly developed facilities.

The method for distributing oil production during the operation of jointly developed facilities is carried out in the following sequence:

i) oil samples are taken from the same facilities operated separately;

ii) selected samples are mixed in proportions of 75-25%, 50-50% and 90-10%, the resulting mixtures are designated as “known mixtures”;

iii) a sample is taken from a well that jointly exploits these oil objects and is designated as an “unknown mixture”;

iv) a sequential analysis of known and unknown mixtures is carried out on a multidimensional gas chromatograph and the resulting chromatograms are loaded into Malcom software , which allows one to determine the contribution of artificially mixed oils in the “unknown mixture”.

A method for assessing the efficiency of simultaneous-separate operation (SSE) of wells, in which oil is produced by a SRP-ESP complex on one tubing hanger is carried out in the following sequence:

Oil samples are taken at the wellhead in three modes:

a) only the sucker rod pump is working

b) only the ESP is working,

c) the sucker rod pump and the ESP are working simultaneously. After sampling in three modes, they are sequentially analyzed geochemically on a multidimensional gas chromatograph, peaks are integrated and star diagrams are constructed. Comparison of the resulting star diagrams by aromatic composition makes it possible to assess whether the WEM of two objects is actually carried out or whether both pumps operate the same object.

The method for determining the vertical isolation of reservoirs in a well is implemented on the basis of the algorithm described below:

i) oil samples are taken immediately after testing formations from lower objects

ii)) their geochemical analysis is carried out on a multidimensional gas chromatograph, peaks are integrated and star diagrams are constructed.

iii) the similarity of the star diagram of oils indicates the vertical connectivity of the layers, and their difference indicates the vertical separation of the layers.

In the third paragraph, a method for compiling geochemical atlases of oil and associated gas is developed. The method is implemented based on the algorithm described below:

i) Oil and associated gases are selected from the wells of the field;

ii) Analysis of selected oil and gas samples is carried out;

iii) Based on the normalization of the aromatic components of oil and the isotopic composition of carbon in associated gases, star diagrams are constructed for each field.

Comparison of star charts allows identification of groups of oil and associated gases to create geochemical atlases for an oil and gas region or basin, with symbols based on genetic parameters such as sedimentation, organic matter (OM) lithology, and thermal maturity.

Based on a comparison of chromatograms, the sedimentation of OM is determined: oils of lake and marine origin are marked in blue () and dark blue () colors, respectively. Based on a comparison of biomarkers, the OM lithology is determined: oils that were generated from clayey source rocks are indicated in green (), while oils that were generated from carbonate source rocks are indicated in yellow () and red () depending on the lithology of their reservoirs. Late - mature oils are indicated by black rectangles (), while oils generated at early maturity or at the peak of maturity are indicated by white () and brown rectangles () (see Figures 3 and 4).

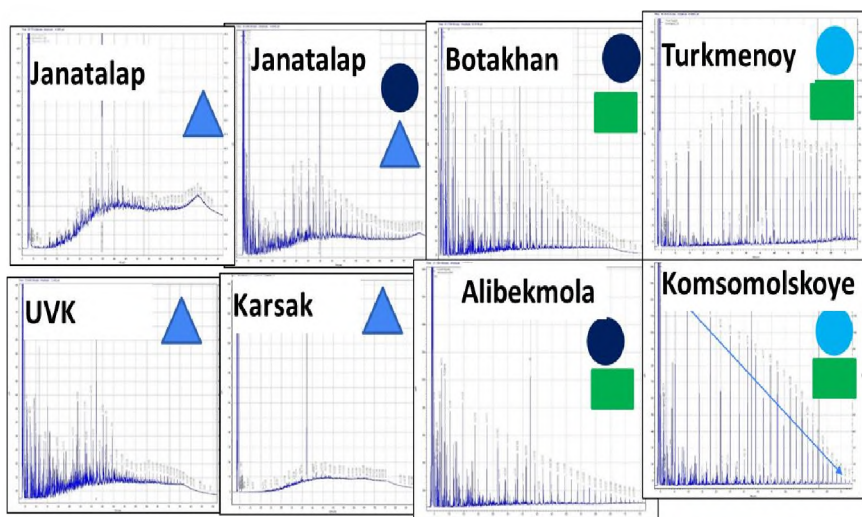


Figure 3 – Chromatograms of biodegraded (blue triangle) and non-biodegraded (green rectangles) oils of marine (blue circles) and lacustrine (blue circles) origin

месторождение	Плотность (кг/м ³)	Кинематическая вязкость при 20 °С (мм ² /с)	Содержание хлористых солей (%)	Температура застывания (°С)	Содержание парафина (%)	Содержание серы(%)	Содержание асфальтены (%)
Жанаталап 65	879	667	374	-36	1,13	0,33	-
ЮВК № 453	870	36,78	1222,36	-54	1,53	0,35	0,1
Ботакхан 121	806	5,21	36,52	-25	2,27	0,16	-
Карсак 68	939	705,9	2485	-18	0,39	0,30	0,21
Алибекмола 103	839	2,48	74,54	-20	2,57	1,53	0,05
Комсомольское Г-3	793	3,98	88	14	11,0	0,05	0,72
Туркменой 54	804	3,95-14	-	18-30	12,1	0,13	-

Figure 4 – Justification of the physicochemical properties of oil based on chromatograms of biodegraded (blue triangle) and non-biodegraded (green rectangles) oil of marine (blue circles) and lake (blue circles) origin

The fourth paragraph presents methods for assessing the quality of oil and petroleum products. Work on assessing oil quality is carried out in the following sequence:

1. Oil is analyzed by gas chromatography to determine the content of paraffin, chloride salts, viscosity and density using an alkanes chromatogram.

If a naphthenic hump is noted on the chromatograms, then such oils have a high density, a high content of chloride salts and high viscosity compared to non-biodegraded oil, in the chromatograms of which all n-alkanes and isoprenoids are present. If oils are of lake origin, then they have a high paraffin content and pour point compared to oil of marine origin;

2. Oil is analyzed by mass spectrometry to determine the content of sulfur and sulfur-containing components.

Sulfur-containing components are identified as dibenzothiophene, methyl dibenzothiophene, which indicate the carbonate origin of the oil;

3. The results obtained are compared and oil quality indicators are determined .

Work on assessing the quality of petroleum products is carried out in the following sequence:

1. An artificial mixture of 11 different aromatic hydrocarbon standards is prepared with the addition of an internal standard.

Used ethylbenzene, paraxelol, meta-xelol, isopropylbenzene, ortho-xelol, n-propyl benzene, 4-ethylbenzene, 3-ethylbenzene, 1,3,5-trimethylbenzene, 2-ethylbenzene, 1,2,4-trimethylbenzene, found in flammable mixtures of hydrocarbons. In this case, one drop (0.1 ml) of each of the specified standards is added to the test tube. The volume obtained is 1.1 ml;

2. Samples of petroleum products are prepared with the addition of an internal standard.

In 50 gr. 1 g of cyclohexane is added. 5-methyl-3-heptanone as internal standard. Weigh 0.9 g on an analytical balance. mixture of aromatic standard and add 0.1 g. basic solution, while the total sample mass should be 1 g. Weigh 0.1 g on an analytical balance. samples of flammable hydrocarbons, in particular gasoline or

kerosene, and add 0.9 g. basic solution, while the total sample mass should be 1 g;

3. A comparison is made of the release time and concentration of 11 aromatic peaks and the internal standard in the artificial mixture and petroleum products;

4. Based on a comparison of aromatic peaks, the quality of petroleum products is assessed (Fig. 5).

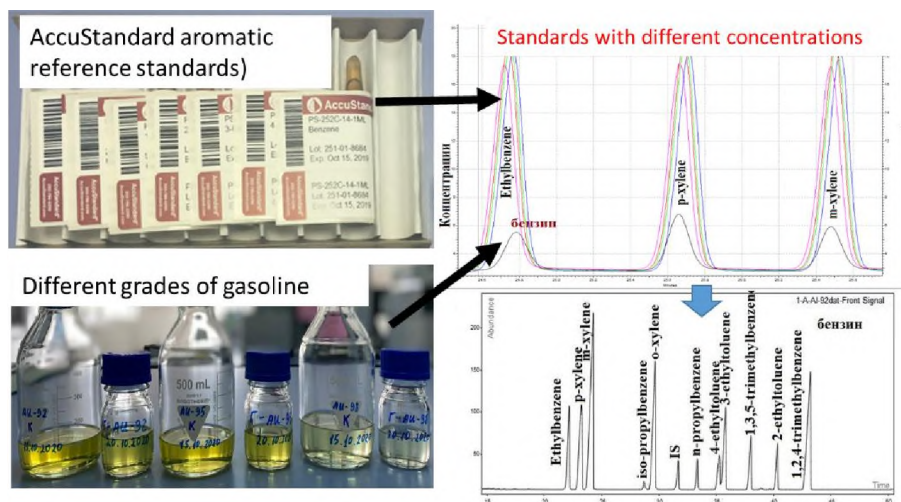


Figure 5 – Chromatograms of gasolines of different brands and aromatic standards

The third chapter presents the results of applying the developed methods in field conditions.

The first paragraph presents geochemical atlases of oil fields of 7 oil and gas basins of the Republic of Kazakhstan (Southern, Eastern and Northern parts of the Caspian basin, Ustryurt-Buzachinsky basin, South Mangyshlaksy basin, South Turgaisky basin, Shu-Sarysy basin) based on the results of geochemical studies of 1550 oil samples (Table 1).

For example, Figure 6 shows the geochemical oil atlas of the fields in the southern part of the Pre-Caspian Basin, where 17 oil groups were identified based on the analysis of 450 oil samples from 31 fields:

Table 1.

Coverage of fields to create a geochemical atlas of oil and gas condensates of the Republic of Kazakhstan

	Oil and gas basins	Number of studied deposits and oil samples		Number of commercial-grade fields and samples suitable for the geochemical atlas	
		Fields	samples	Fields	samples
1	Southern part of the Caspian basin	48	500	41	450
2	Eastern part of the Caspian basin	10	130	8	130
3	Northern part of the Caspian basin	3	25	3	25
4	Ustyurt-Buzachinsky basin	10	55	8	55
5	Mangishlak basin	23	550	20	450
6	South Turgai basin	22	400	21	400
7	Shu-Sarysu basin	4	40	4	40
	Total number of samples	120	1700	104	1550

the first group is formed by the oils of sub-salt carbonate deposits of three giant fields (Kashagan, Tengiz, Korolevskoye). *The second group* is formed by the oils of the S. Nurzhanov and Zapadnaya Prorva fields, which are similar in their biomarker composition. The oils of the Borankol, Vostochnaya Kokarna, and Kisimbay fields belong to *the third group*, while *the fourth group* includes the oils of the South-west Saizyube, Tolkyin, Kulzhan, Eastern Saizyube, Zapadny Elemes, Lebyazhye, and Bakhyt

structures. Despite their close location, the oils of the Karasor, Aktobe, and Dosmukhambetovskoye fields differ and form separate groups (5, 6, and 7), respectively.

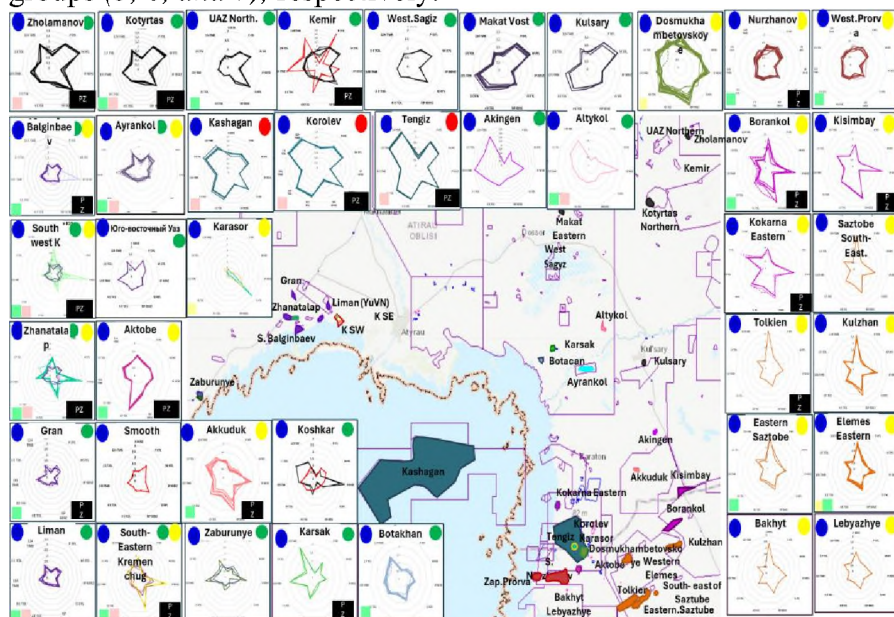


Figure 6 – Geochemical atlas of oil fields in the southern part of the Caspian basin

It should be noted that the aforementioned fields are located in terrigenous deposits, but according to the results of biomarker analysis, these oil samples were formed from marine carbonate organic matter and are accordingly marked with yellow circles on the maps.

The oils of the Akkuduk and Botakan fields can be attributed to the *eighth and ninth groups*, while the oils of the Eastern Makat and Kulsary fields belong to the *tenth group*, although the biomarker composition of the oils from these fields differs slightly. Groups 11 and 12 include the oils of the Altykol and Akingen fields, respectively. In turn, the *thirteenth group* unites the oils of the Zholamanov, Northern Kotyrtas, Uaz, Kemir, and western Sagyz fields, which share close distribution profiles of aromatic

components despite minor variations in their detailed biomarker composition.

However, our studies demonstrate that the oils of the Zholamanov field are characterized by a specific set of biomarkers, which ensures their isolated position on principal component analysis (PCA) diagrams. The different origins of the oils from the Kulsary, Botakan, Akkuduk, and Akingen fields are also supported by our previous studies on the $\delta^{13}\text{C}$ values of individual n-alkanes in their oils and their biomarker composition. Within the boundaries of the Balgimbayev, South-western Kamyshitovoe, South eastern Kamyshitovoe, Gran, Liman, and Zhanatalap fields, two different oil types are noted, constituting *groups 14 and 15*, respectively. The oils of Ayrankol form *group 16*. The oils of Zaburunye can be attributed to the final group. The oils of the Zhanatalap and Yugo-Zapadnoe Kamyshitovoe fields were formed from two oil sources. Interestingly, according to biomarker analysis data, these oil fingerprints belong to two different source rocks with different depositional conditions and types—of clayey and carbonate origin. The above data may indicate high petroleum potential between the deposits of fields whose oils have a similar composition and fall into the same group with similar genetic parameters.

This section also provides examples of the successful application of the developed methods for assessing hydrodynamic connectivity between reservoir layers within each field, presented in alphabetical order, which allows for identifying oil subgroups and determining their hydrodynamic connectivity within the field.

This chapter also outlines the results of testing and verification of the author's cluster analysis methodology (Ward's method) aimed at assessing hydrodynamic connectivity between reservoir layers. A comprehensive validation of the proposed approach was carried out by comparing the results of geochemical fingerprinting with data from traditional field methods using the Nuraly, Kozhasay, Alibekmola, Eastern Uaz, and Northern Uaz fields as case studies. Systematization of the successful application examples confirmed the high resolution of the approach in tasks related to identifying oil subgroups and characterizing filtration flows, thereby optimizing

time and computational resources. The analysis demonstrated high convergence of geochemical data with field studies and updated geological reservoir models built on the basis of modern seismic attributes. In the Nuraly field, stable connectivity between wells was confirmed by tracer indicators (thiourea) and correlation with a refined tectonic fault model.

In the Alibekmola field, the effectiveness of the oil fingerprinting clusterization of the "orange" groups was confirmed by the high filtration rate of the indicators (uranine, rhodamine). An investigation of 25 oil samples showed that the proposed method possesses high sensitivity: deviations in the composition of individual samples from general trends are confirmed by biomarker composition, which allows for identifying errors in traditional laboratory analyses. The effectiveness of the approach was also confirmed by comparison with pulse-code interference testing (PIT) data and Stiff diagrams of formation waters in the Kozhasay field, where the identified groups correlate completely with field measurements. In the Vostochny and Severny Uaz fields, a complex of biomarker analysis and PVT-dependency studies made it possible to unequivocally prove the absence of hydrodynamic connectivity between Triassic deposits. The integration of geochemical data significantly refined the understanding of the object's structure, and the convergence of results across various fields confirms the reliability of the developed methodology.

The second paragraph of the chapter presents geochemical atlases of associated gas from four oil and gas basins of the Republic of Kazakhstan based on the results of analyzes of 80 gas samples from 23 fields (Table 2).

For example, Figure 7 shows a geochemical atlas of associated gas fields of the southern part of the Caspian basin, where 5 main groups are noted: *The first* group includes gases from the Northern Kotyrtas and Zholamanov fields, while gases from the Eastern Makat and Liman fields form *the second and third* groups, respectively. Although the stellar diagrams of the gases of S. Nurzhanov and one sample from Western Prorva have little similarity, they belong to *the fourth and fifth* groups. The identified groups based on this gas study

are also confirmed by the results of fingerprinting of oil from these fields.

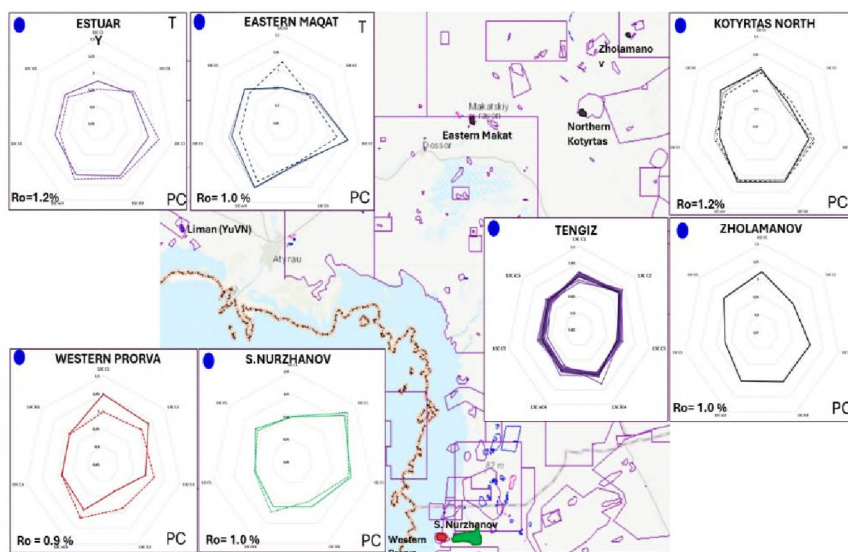


Figure 7 – Geochemical atlas of associated gas fields in the southern part of the Caspian basin by carbon isotope composition

Table 2.

Coverage of fields to create a geochemical atlas of associated gas of the Republic of Kazakhstan

	Oil and gas basins of the Republic of Kazakhstan	Number of deposits	Number of samples
1	Southern part of the Caspian basin	7	34
	Northern part of the Caspian basin	1	12
2	Mangishlak basin	8	20
3	South Turgai basin	4	8
4	Shu-Sarysu basin	3	6
	Total	23	80

The third paragraph presents the application of the developed methods for assessing the quality of oil and petroleum products (gasoline and kerosene). The essence of the method developed by the author for assessing the quality of oil is that oils with good quality have the presence of all alkanes in their chromatograms, while oils with poor quality are characterized by the absence of n-alkanes or the presence of a naphthenic hump, which indicates the biodegradation of oil. Biodegraded oils have high density, high viscosity and high content of chloride salts, which are likely caused by the action of bacteria in reservoirs. Another parameter of oil quality indicators according to the proposed method is that oils of lake origin have a high paraffin content compared to oil of marine origin. The dissertation shows geochemical atlases of oil from about 115 different fields of the Republic of Kazakhstan, where biodegraded oils were marked with a triangle, while oils that were not subject to biodegradation were marked with a green rectangle.

The essence of the method developed by the author for assessing the quality of petroleum products is to predict the grade of gasoline and kerosene using a multidimensional gas chromatograph. For example, Figure 8 shows a star diagram of 10 samples of gasoline of the AI-92, AI-95 and AI-98 brands, selected at 4 different anonymous gas stations (A, B, C, D) in the city of Atyrau (Kazakhstan). As can be seen from Figure 7, gasoline of the same brand from different gas stations has an identical molecular composition, with the exception of gasoline of the AI-92 brand at gas station D.

It is likely that gas station D may indeed sell gasoline with an octane number that does not correspond to the declared class or add additives to increase the octane number. High concentrations of 1,3,5-trimethylbenzene (mesitylene) and low concentrations of 1,2,4-trimethylbenzene in the studied gasoline sample AI-98 are explained by the fact that in gasoline 1,3,5-trimethylbenzene (mesitylene) has a high detonation resistance, while 1,2,4-trimethylbenzene (pseudocumene) has low detonation resistance. The importance of this method is that it can be used as an independent assessment and continuous monitoring of gasoline quality at gas stations in different cities.

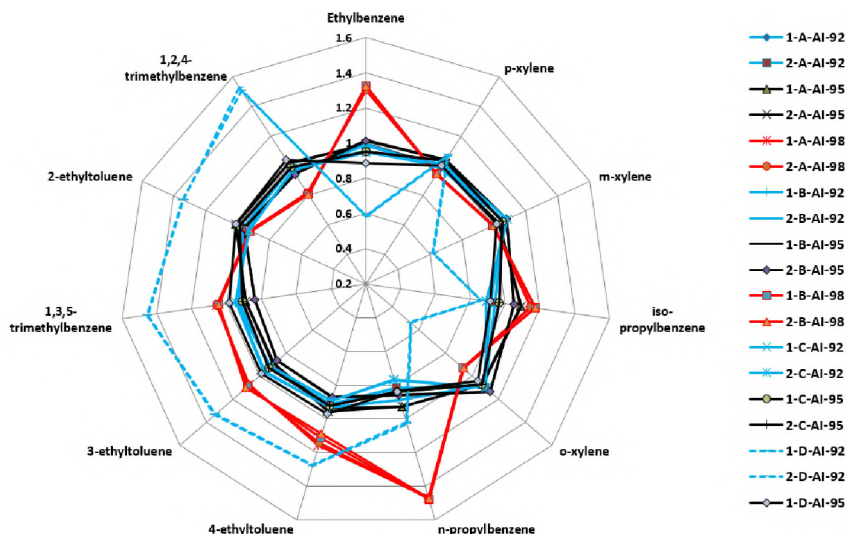


Figure 8 – Star diagram of the studied gasoline samples based on the results of LTM-MD-GC

The significance of developing this area lies in the fact that comparing data on crude oil and finished gasolines will eventually make it possible to determine precisely which field feedstocks yield high-octane fuel (or vice versa). This information is of key importance for refineries when selecting potential customers and optimizing production processes.

The main advantage of this method is that it represents the most scientifically grounded approach for analyzing the composition of gasolines across various grades, even at trace concentrations (100 mg is sufficient). All samples are analyzed in duplicate using LTM-MD-GC to ensure research reliability, and comparing the duplicate results consistently yields identical outcomes, which indicates high reliability and eliminates laboratory errors ranging from sampling to data processing.

The geochemical atlases created in this dissertation have quite a lot of advantages:

1. Provides valuable information on assessing the hydrodynamic connectivity between reservoirs and the genetic origin of hydrocarbons within each basin;

2. Symbols for genetic parameters on geochemical atlases allow not only to identify genetic types of oil, but also contain information about the composition of oil. For example, oils of lake origin may have a higher wax content compared to oils of marine origin. Oils from carbonate reservoirs have a relatively high content of sulfur and sulfur-containing components compared to oils from terrigenous reservoirs. Oils of late thermal maturity have high gas content and saturation pressure compared to oils formed at the peak of maturity or early maturity. For example, the abnormally low values of gas content and saturation pressure in Karasor oils are justified by their low thermal maturity;

3. The use of geochemical atlases of oil and gas in the cycle of geological exploration allows us to predict the migration paths of hydrocarbons, thereby identifying promising objects for seismic exploration and drilling, which can significantly reduce financial and time costs. In this work, about thirty promising zones of possible hydrocarbon accumulations were proposed, which should be confirmed by seismic and logging data;

4. The geochemical atlas database allows you to determine the source of the oil sample. For example, the South oil company delivered encoded oil samples without the names of the fields. After the analysis, a search was carried out for similarities in the composition of the oil from the database and it was found that the oil was similar to the oil from Akshabulak Eastern, which was confirmed by the customer;

5. The presence of the atlas allows you to avoid carrying out expensive traditional types of research to determine the hydrodynamic connection of objects, such as tracer, hydrotesting, PLT ;

6. The presence of a database on the isotopic composition of carbon in gases enables to discern not only a genetic link between different gases and also to assign unknown gases to a specific basin if the delivered samples are coded;

7. The Atlas will allow companies involved in the transportation of oil and gas to take into account the properties of the pumped agents without additional analysis. For example, oils of carbonate origin have a relatively high content of sulfur and sulfur-containing components (hydrogen sulfide, mercaptans, ethyl mercaptans, etc.), which leads to pipeline corrosion, while oils of lake origin have a relatively high paraffin content, which leads to the formation of paraffin deposits during transportation.

The described examples of the use of geochemical atlases to substantiate the component composition of hydrocarbons and increase the efficiency of oil and gas prospecting work show the indisputable feasibility of their use in practice, since with their help, areas that would be conserved using traditional methods are added to promising zones of hydrocarbon accumulation.

MAIN CONCLUSIONS AND RECOMMENDATIONS

1. A review of existing methods (tracer study, IKG, formation water analysis, PVT analysis of oil properties, well logging, seismic and traditional geochemical studies, integrated production control geophysical studies) used to determine the hydrodynamic connection between layers with detailed descriptions of them was carried out. shortcomings. It is shown that existing methods turned out to be insufficiently effective and the use of geochemical research is an urgent task to determine the hydrodynamic connection between layers and the quantitative distribution of hydrocarbon production of jointly operated objects [1, 2, 3].

2. Methods have been developed for determining hydrodynamic connections based on geochemical analysis of oil and gas [14-16, 18-20, 25-26]. The methods are implemented based on the algorithm described below:

- ✓ oil is selected from geological objects between which it is planned to determine the hydrodynamic connection;

- ✓ oil and gas analyzes are carried out to determine the component and isotopic composition of hydrocarbons;

- ✓ based on the normalization of the aromatic components of oil and the isotopic composition of associated gases, star diagrams are constructed for each sample;

- ✓ Based on a comparison of star diagrams, a conclusion is made about the presence or absence of a hydrodynamic connection between objects.

3. Methods for distributing oil production and assessing the efficiency of operation of jointly developed facilities are proposed [11, 23-24, 30]:

- ✓ method of distribution of oil production during the operation of jointly developed facilities;

- ✓ method for assessing the efficiency of simultaneous-separate operation (SSE) of wells;

- ✓ method for determining the vertical isolation of reservoirs in a well.

The listed methods provide a scientific basis for monitoring production in the event of mixing of oil when developing several objects with one well.

4. A method for compiling geochemical atlases of oil and associated gas has been developed [31-37]. The method is implemented based on the algorithm described below:

1. oil and associated gases are sampled from field wells;
2. analysis of selected oil and gas samples is carried out;
3. Based on the normalization of the aromatic components of oil and the isotopic composition of carbon in associated gases, star diagrams are constructed for each field;
4. geochemical atlases are created for the oil and gas region or basin.

5. Methods have been developed to assess the quality of oil and petroleum products [22]. Work on assessing oil quality is carried out in the following sequence:

- ✓ oil is analyzed using gas chromatography to determine the content of paraffin, chloride salts, viscosity and density using an alkanes chromatogram;

- ✓ oil is analyzed by mass spectrometry to determine the content of sulfur and sulfur-containing components;

- ✓ the results obtained are compared and oil quality indicators are determined;

Work on assessing the quality of petroleum products is carried out in the following sequence:

- ✓ an artificial mixture of standards of 11 different aromatic hydrocarbons is prepared with the addition of an internal standard;

- ✓ samples of petroleum products (gasoline, kerosene) are prepared with the addition of an internal standard;

- ✓ An artificial mixture of aromatic standards and petroleum products is analyzed sequentially;

- ✓ a comparison is made of the release time and concentration of 11 aromatic peaks and the internal standard in the artificial mixture and petroleum products;

- ✓ Based on a comparison of aromatic peaks, the quality of petroleum products (grades of gasoline and kerosene) is assessed.

6. The developed methods were put into practice to create geochemical atlases of oil and gas based on the analysis of 1700 oil samples and 45 associated gas samples from 120 oil and gas fields located in 7 oil and gas basins of the Republic of Kazakhstan (Southern, Eastern and Northern parts of the Caspian basin, Ustryurt-Buzachinsky basin, South Mangyshlak basin, South Turgai basin, Shu-Sarysu basin) [1-41].

7. Validation of the proposed method was carried out by comparing the results of geochemical fingerprinting with conventional field data (tracer tests, IKG/pressure restoration, formation water analysis, oil PVT property analysis) using the Nuraly, Kozhasay, Alibekmola, East and North Uaz fields as case studies. Systematization of the testing results confirmed the high resolution of the method in differentiating oil subgroups and identifying flow paths, which significantly optimizes time and computational costs. A high degree of convergence between the geochemical data, field surveys, and refined geological reservoir models constructed using advanced seismic surveys was revealed. The developed method for determining the quality of oil and petroleum products received a patent of the Republic of Kazakhstan No. 7172 dated June 03, 2022.

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