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ANALYSIS OF THE INFLUENCE OF THE COMPOSITION AND PROPERTIES OF OILS ON THEIR QUALITY BASED ON FUZZY CLUSTERING

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Summary. The submitted paper studies published data and summarizes contemporary views concerning classification of tight oil reserves and evaluation of their quality. In recent years there has been an increase in the production of tight oil reserves, which are difficult to extract because of their anomalous properties, as well as because of difficult geological conditions, which makes it important and necessary to study the qualitative properties of tight oil. The paper offers results of the analysis and systematization of indicators of the properties of oil samples collected at various Kazakhstani fields and their classification prepared using fuzzy cluster analysis algorithm. Three groups of signs were considered as classification attributes of various types of tight oil reserves: 1) signs characterizing the composition, this is the content of sulfur, chlorides; 2) properties, this group includes oil density and viscosity, 3) mode of occurrence, i.e. in-situ permeability. Preliminary analysis was completed to determine current status of the issue of tight oil reserves classification and quality evaluation. A review of classification results of tight oil reserves demonstrated the need to break down the entire data set (assemblage) into uniform groups using a series of classification attributes, for which fuzzy cluster analysis is the most appropriate solution. A parameter characterizing oil quality was offered, too. Three clusters have been obtained, each of which characterizes the difficulty of extraction, linguistic rules of conformity of a lot of oil characteristics and total quality factor have been formulated.

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1. Introduction

In recent years production of tight oil reserves has been observed to be growing, which causes a host of process technology and economical challenges in various stages of crude oil production, shipping and processing. While putting on stream tight oil reserves characterized by high density and viscosity, high content of sulfur, paraffins, tars and heavy metals degrades chemical properties of petroleum feedstock and associated process technology indicators, it also amplifies environmental impact thus increasing environmental costs incurred by such territories, which ultimately affects technical and economic performance of development projects. Recent years an expansion in the processing of these types of crude have seen that are hard to produce due to their anomalous properties as well as due to complex geological settings, which makes it important and essential to study qualitative properties of tight oil. Some specific features of physical and chemical properties of tight oils and their modes of occurrence were reviewed in papers (Максутов и др., 2005; Ященко и Полищук, 2016). However qualitative parameters of such crudes and in particular of the oils found in Kazakhstan have not been studied in sufficient detail thus making it more difficult to solve challenges in oil production and shipping as well as process issues in petrochemistry and petroleum refining in the context of increasing production of tight oil over the recent years. The above mentioned problems are particularly relevant for Ka-

zakhstan. Hence, this paper presents the results of the analysis of properties and composition of various types of tight oil collected at Kazakhstani fields using a classification on the basis of attributes that define their quality. A review of classification results of tight oil reserves was performed, and it demonstrated the need to break down the entire data set (assemblage) into uniform groups using a series of classification attributes, for the purpose whereof cluster analysis is the most appropriate solution (Akhmetov et al., 2018). In this connection and in order to provide substantiation to the selected method, this paper reviews the essence of cluster analysis, the results of its application, the evaluation of the level of oil production complexity and the effect of this complexity on the performance indicator.

2. A brief review of the study and classification of tight oils

It follows from the review of various research papers that oil properties have been studied in various aspects. This is connected to the fact that oil is a fairly complex natural object. Thus, for example, various papers study the genesis of oil and formation of oil deposits, the issues of oil field prospecting and exploration, studying chemical composition of crudes, modes of their occurrence and designing methods of refining.

Solving all of these and related matters is feasible if a practical and integral classification is available that enables a sufficiently full and clear characterization of crude oil from both science and practice points of view. This will help select a valid method of reservoir stimulation. Along with this, creating a classification of this kind is a fairly difficult task that according to many researchers has not received a satisfactory solution (Максутов и др., 2005; Ященко и Полищук, 2016; Akhmetov et al., 2018; Лисовский и Халимов, 2009).

Many papers have been dedicated to oil classification attempts. Experts believe that the classifications reviewed are rather notional because oil properties are related to its composition and to geological features of deposits (Классификация нефтей, https://studfiles.net/preview/1772355/page:2/). "Unusual oil" (as Santos et al. call it (2014)) is primarily heavy and extra-heavy crude oils and bitumens, which account for a significant potion of total global oil reserves. These resources that generally feature high-viscosity crudes require additional efforts during production and when shipping to various destinations. A review provided in (Santos et al., 2014) describes the principal properties of high-viscosity crude oil and compares traditional and latest methods for its production and shipping. The main parameters of viscous crudes are discussed so as to identify their properties that affect ability of such oil to flow when it is produced from reservoir and shipping by pipeline. Chemical composition is one of the main properties and it has a significant effect on other parameters including density and viscosity. Presented further in the review are enhanced oil recovery (EOR) methods followed by a discussion of shipping methods and pipeline construction methods.

Paul J.Nardone (2009) compared the distribution of heavy oil and bitumen with the distribution of organic folding and tectonic disturbances of the mesozoic and neozoic sediments.

Ященко и Полищук (2016) reviewed and summarized published data and offered a typification of tight oils and their classification on the basis of the criterion that they proposed and named quality index. They point out that expansion of tight oil exploration and development activities occurring in recent years dictates the need for a study of qualitative properties of such crudes. Publication (Максутов и др., 2005) analyzed the physical and chemical properties of tight oils and their occurrence conditions. One of the reasons why studies in this domain have not been sufficient is the broad variety of existing crudes in terms of their composition and properties, and this in turn makes it more difficult to solve challenges in oil production and in transportation of hydrocarbon feedstock, as well as process issues in petrochemistry and oil refining. This explains the interest of researchers in this problem. Thus, relevant studies were completed in (Ященко и Полищук, 2016) in order to develop a classification of crude oils in terms of their quality and for the purpose of applying this classification when analyzing qualitative parameters of various types of tight oil reserves.

Authors of this paper indicate that on the basis of the definition of tight oil reserves proposed in (Лисовский и Халимов, 2009) they defined the key identification principles and criteria used to rate reserves as tight oil. After analyzing and summarizing these proposals and proposals offered in various publications by other experts, authors of (Ященко и Полищук, 2016) presented for consideration a list of the main types of tight oil and listed their properties and mode of occurrence, which are used to identify crudes as tight oil reserves. These parameters include a series of attributes such as depth of occurrence, water cut, oil properties, in-situ permeability, etc.

It is worth noting that various publications offer different definitions of tight oil reserves, hence the challenges of classifying these.

Thus for example, in most cases such as those indicated in (Ященко и Полищук, 2016; Лисовский и Халимов, 2009; Шпуров и др., 2014) "...tight oil reserves include oil reserves composed of low-mobility oil (including high-viscosity or high-density crude with high content of solid paraffins), oils featuring high or low gas-oil ratio (over 500 m^3/t or under 200 m^3/t respectively) or oils that contain aggressive components (hydrogen sulfide, carbon dioxide) in dissolved gas and/or in free gas in such amounts that require using specialized equipment in well drilling operations and in production of crude oil". Crudes included in this group are called oils with anomalous physical and chemical properties (Ященко и Полищук, 2016). Publication (Ященко и Полищук, 2016) also puts in this group the crudes characterized by high content of metals (primarily vanadium and nickel), which are classified as heavy metals as they increase environmental risks.

According to available publications, the second group of tight oil reserves are the crudes that occur in complex settings (found in formations and deposits with complex geology, in oil-water and gas-oil zones, in low-permeability and low-porosity reservoirs, with abnormally high or abnormally low reservoir temperature, etc.) as well as oil reserves occurring in permafrost areas and offshore (Шпуров и др., 2014). Having summarized the criteria used to classify oil reserves as tight oil, publication (Ященко и Полищук, 2016) provides a table that lists the main types of tight oil and that was put together on the basis of the studies presented in a large number of scientific publications (Ященко и Полищук, 2016; Лисовский и Халимов, 2009; Шпуров и др., 2014). According to (Антониади и Савенок, 2013), oil reserves are classified as tight oil on the basis of quality criteria: heavy oil (density over 0.92 g/cm^3); high-viscosity oil (over 30 mPa·s at standard conditions) and mode of occurrence: very low reservoir permeability (below 0.05 μm^2).

It was proposed in (Ященко и Полищук, 2016) to use integral indicator for evaluation of quality parameters of crudes in oil fields and oil basins. This approach was used by the authors of (Крицкая и Чиж, 2013; Клубков, 2015) when evaluating and analyzing trends in spatial changes of oil quality indicators in oil-bearing territories of various regions, countries and continents. The oil quality index introduced in (Елисеева и Лукьянов, 2014) is determined as the inverse value of the above mentioned indicator and it turned out to be sufficiently convenient for the analysis of specific quality features of various types of tight oil reserves (Ященко и Полищук, 2016). Here, larger values of oil quality index correspond to higher quality of oil and vice versa, which is convenient when comparing various types of tight oil in terms of quality.

Publication (Раупов и др., 2014) lists the results of studies of optical properties of oil. This work analyzed results of laboratory tests of density, viscosity, optical density and light absorption indices of oil samples collected in various oil provinces of Russia. A brief description of photocolorimetric oil sample analysis method is provided, too.

The publication describes international and Russian classifications of oil indicating that common crudes feature increased viscosity and medium density. It classifies crudes by types using approximation behavior of density and light absorption coefficient RMS value and identifies 3 classes of oil with sufficiently high approximation reliability as follows: light oil (density $\rho < 870$ kg/m^3), medium (density $870 < \rho < 920$ kg/m^3), and heavy oil (density $\rho > 920$ kg/m^3). There are 3 classes of oil identified in the paper using viscosity approximation behavior, too: low-viscosity oil ($1 < \mu < 5$ mPa·s), elevated-viscosity oil ($5 < \mu < 30$ mPa·s), and high-viscosity oil ($\mu > 30$ mPa·s) (Раупов и др., 2014).

The authors proposed a solution for the enhancement of optical oil tests and for the monitoring of oil field development. Results of the completed studies help improve accuracy and reliability of production geology monitoring of oil field development and help to obtain reliable production geology data in real time using appropriate techniques (Раупов и др., 2014).

At the same time, one can say definitively that none of the physical or chemical crude classifications can be recognized as universal. Besides, classification has to take into account oil occurrence mode, too. All of the above mentioned considerations create uncertainty in classification criteria and dictate the need to take this factor into account when tackling classification tasks.

These questions are on the agenda of discussions and conversations at various events such as conferences, seminars, etc. For example, at the XI World Petroleum Congress held in Houston in 1987, a classification was proposed that divides hydrocarbons in oil and bitumen (for convenience referred to as "classification 1" (Раупов и др., 2014). It was proposed to classify as bitumens those hydrocarbons that have in-situ density exceeding 1000 kg/m^3 and dynamic viscosity over 10000 mPa·s. while crude oils were divided in four classes: light, medium, heavy, and extra-heavy oil (Раупов и др., 2014). Certain publications have been dedicated to the evaluation and analysis of patterns in the changes of qualitative indicators of

crude oil from various regions. For example, publication (Ященко и Полищук, 2016) makes references to similar works and discusses the possibility of applying an integral oil quality indicator. This indicator enables comparative evaluation of oil quality. A similar parameter is calculated by summarizing all properties of oil under consideration using the formula proposed in (Karazhanova et al., 2019). Apparently, there have been very many publications issued to date on various issues of tight oil reserves, and it is not possible to cover this great variety in one brief study.

The analysis of the structure of tight oil reserves and trends in oil growth rates that was performed in the reviewed publications indicates that tight oil fields are characterized by low and unstable well production rates, and operation of these wells requires designing and implementing modern and expensive technology solutions (Ященко и Полищук, 2016; Akhmetov et al., 2018; Антониади и Савенок, 2013; Karazhanova et al., 2019).

3. Cluster analysis and evaluation of tight oil quality using a series of attributes

Relevant publications give evidence of a large number of studies that have proposed over one hundred various clustering algorithms including hierarchical and non-hierarchical cluster analysis methods and fuzzy clustering (Akhmetov et al., 2018; Efendiyev et al., 2016; Efendiyev et al., 2018; Aliev and Guirimov, 2014; Turksen, 2013).

In recent years, these methods have been broadly applied in various spheres. Publications on clustering methods outline operating principles used in algorithms of "conventional cluster analysis methods" and their difference from unconventional i.e. fuzzy clustering methods. These works demonstrate the advantages of fuzzy clustering (Akhmetov et al., 2018).

With the aim of classifying tight oil reserves, publication (Akhmetov et al., 2018) performed clustering based on a fuzzy cluster analysis algorithm. For this purpose, data concerning oil viscosity, density and in-situ permeability were collected from a large number of petroleum fields in Kazakhstan. The following three indicators were selected for our cluster analysis: oil viscosity, oil density, and reservoir permeability. Completing a program of fuzzy cluster analysis produced four classes, and each of them characterizes the level of complexity of oil production (Akhmetov et al., 2018).

Bearing in mind that crude oil from various fields differs in composition too, this article adds the attributes that characterize oil composition in addition to the above mentioned indicators. This cluster analysis was performed using test results of Kazakhstani crudes. Thus, sulfur and chloride contents were added to the list of parameters.

The analysis in question was performed for the following five parameters: concentrations of sulfur and chlorides, density, viscosity and in-situ permeability. Using the fuzzy cluster analysis algorithm for the fields under review helps to identify three groups that are uniform in terms of composition, properties and mode of oil occurrence. Results of these calculations are provided in (Karazhanova et al., 2019). On the basis of these results the present paper offers results of the study of the membership function changes for each of the highlighted indicators together with the parameter that for the purpose of convenience was named "oil quality indicator". Behavior graphs for the specified membership functions are displayed in Fig. (a to e). These diagrams help to estimate limit values of the attributes within each of the clusters produced. It follows from the data analysis that the data under review contain the attributes whose values vary in a broad range.

It was mentioned earlier that the data concerning oil properties, composition and modes of occurrence were divided in three uniform groups as the result of cluster analysis.

The Table specifies limit values of the attributes within each cluster. This analysis also helps to determine correlation of qualitative assessments of these attributes with the values of oil quality indicator by means of fuzzy rules, which can be defined using the results listed in the Table .

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The above mentioned fuzzy rules based on the "if ... then ..." principle help to evaluate oil quality using a set of attributes that characterize its composition, properties and mode of occurrence.

Using this indicator is quite convenient in the analysis of qualitative properties of various types of tight oil reserves. Here, larger values of oil quality index correspond to higher quality of oil and vice versa, which is logical and convenient when comparing quality of various types of tight oil that represent different fields.

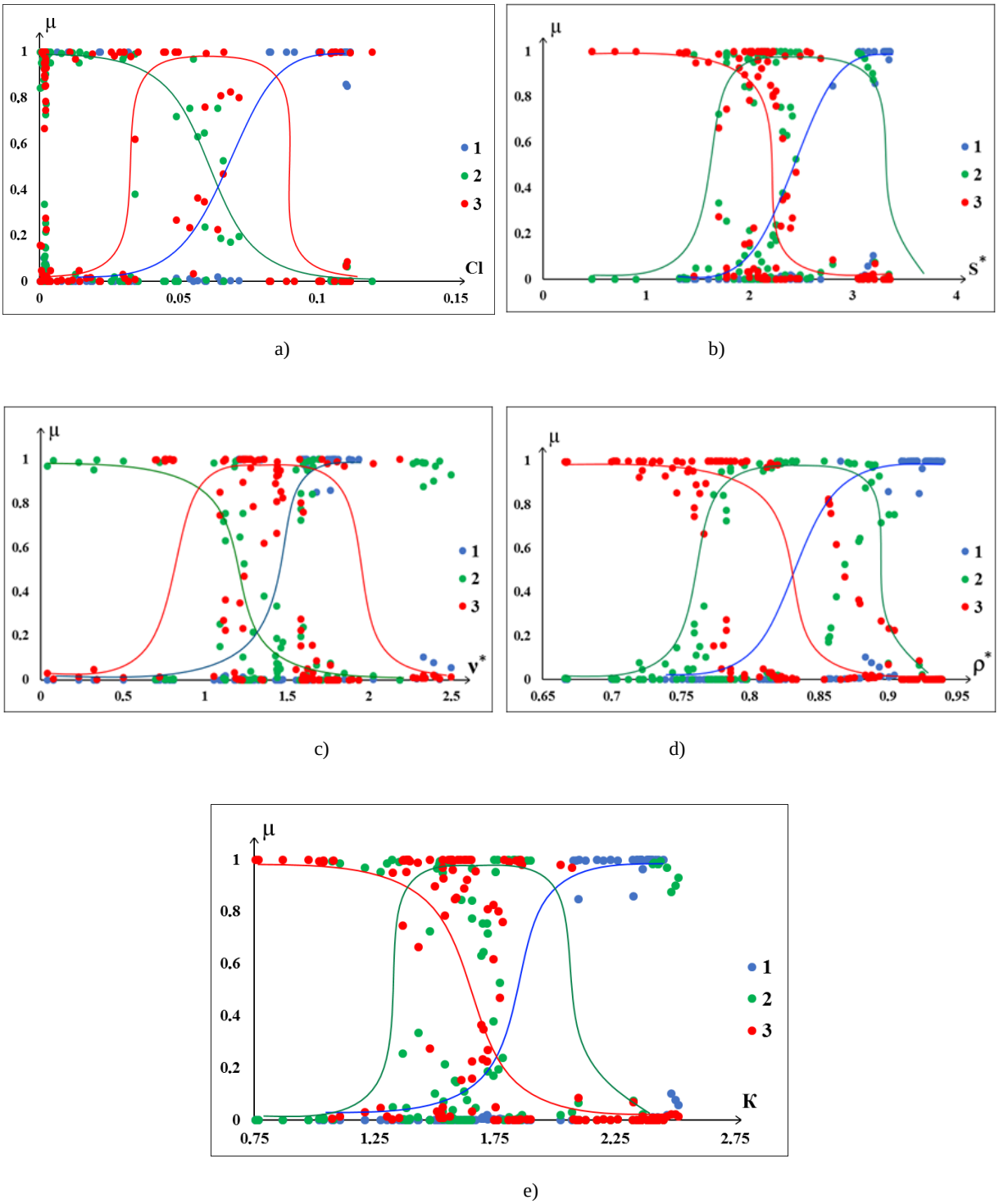


Fig. Membership functions for different clusters of: a) chlorides concentration, b) converted sulfur concentration in oil, c) converted viscosity, d) oil to water density ratio, e) corresponding values of oil quality index

Table

Limit values of classification attributes by clusters

Attributes	IF			AND			AND			AND
Clusters	Chlorides concentration			S* = Converted sulfur concentration log (S x 1000)			v* = Converted viscosity log (v x 10)			
	Quant.	Qualit.		Quant.	Qualit.		Quant.	Qualit.		
1	Cl ≥ 0.08	high		S* ≥ 3	high		v* ≥ 1.7	high		
2	Cl ≤ 0.03	low		2 < S* < 3	medium		v* ≤ 1	low		
3	0.03 < Cl < 0.08	medium		S* ≤ 2	low		1 < v* < 1.7	medium		

AND			THEN		
ρ* = ρ/ρwater - oil to water density ratio			Composite oil quality index		
Quant.	Qualit.		Quant.	Qualit.	
ρ* ≥ 0.88	high		K ≥ 2.2	low	
0.78 < ρ* < 0.88	medium		1.7 < K < 2.2	medium	
ρ* ≤ 0.78	low		K ≤ 1.7	high	

*Note: Cl, %; S, %; ν, mPa*s; ρ, kg/m^3.

4. Conclusion

The paper lists results of the studies that were presented in various research articles, together with the results of the review that was performed on the basis of these publications in order to analyze methods and principles of various classifications of tight oil reserves, which can be articulated as follows:

- a summary was prepared of methods, methodology concepts and scholarly views concerning requirements towards classification of tight oil reserves and evaluation of the level of oil production complexity; a substantiation was provided for the fundamentals of designing and practical implementation of classification methodology for fields of different types (oil, oil and gas, gas fields) using a set of attributes that enable evaluating the level of complexity of producing certain reserves;
- a classification of tight oil fields was proposed by analyzing and summarizing information about a set of attributes that characterize composition, properties and modes of occurrence of crude oil in certain Kazakhstani fields using a fuzzy cluster analysis algorithm;
- a parameter was proposed that describes the level of complexity of producing oil reserves, which includes such parameters as composition, properties and oil occurrence modes, and fuzzy rules were defined that enable evaluation of oil production complexity under uncertainty conditions;
- the results of classification of tight oil reserves have demonstrated that in addition to the fields where oil reserves feature composition and properties that degrade their quality there is a large portion of tight reserves associated with such conditions as low-permeability reservoirs, which is typical for most Kazakhstani fields.

A large number of researches were devoted to studies of analysis questions, classification and quality assessment of hard to recover oil, interesting results have accumulated. In the performed works the various methodological approaches to the oil classification were proposed, highlighting their applications, quantitative assessment of complexity of various oils reserve recovery. The evaluations are based on a statistical analysis that takes into account almost all the characteristics that influence technological specificities of fields'development and investment capital. The high effectiveness of hard to recover oil field's development can be ensured only by validated classification considering the main factors with ranking the complexity of hydrocarbon reserve recovery. Based on the classification, the comparative evaluation of the complicating factors which are classified into natural, technological and economical in the literature seems possible. Moreover, the hard to recover hydrocarbons reserves fields' development is in important condition for the implementation of the energy strategy for the industry as a whole.

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АНАЛИЗ ВЛИЯНИЯ СОСТАВА И СВОЙСТВ НЕФТИ НА ИХ КАЧЕСТВО НА ОСНОВЕ НЕЧЕТКОЙ КЛАСТЕРИЗАЦИИ

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Резюме. В представленной статье исследуются опубликованные данные и обобщаются современные взгляды на классификацию запасов трудноизвлекаемой нефти и на оценку их качества. В последние годы наблюдается рост добычи трудноизвлекаемых запасов нефти и расширение переработки этих типов нефти, которые трудно добывать из-за их аномальных свойств, а также из-за сложных геологических условий, что делает крайне важным и необходимым изучение качественных свойств трудноизвлекаемой (тяжелой) нефти. В статье представлены результаты анализа и систематизации показателей свойств проб нефти, отобранных на различных месторождениях Казахстана, и их классификации, подготовленной с использованием алгоритма нечеткого кластерного анализа. В качестве классификационных признаков различных типов запасов трудноизвлекаемой нефти рассматривались три группы признаков: 1) признаки, характеризующие состав, это содержание серы, хлоридов; 2) свойства, в эту группу входят плотность и вязкость нефти, 3) форма проявления, т.е. проницаемость на

месте. Проведен предварительный анализ для определения текущего состояния вопроса классификации запасов и оценки качества трудноизвлекаемых запасов нефти. Обзор результатов классификации запасов трудноизвлекаемой нефти продемонстрировал необходимость разбить весь набор данных (совокупность) на однородные группы с использованием ряда классификационных признаков, для чего наиболее подходящим решением является нечеткий кластерный анализ. Также в данной статье был предложен параметр, характеризующий качество нефти. Получены три кластера, каждый из которых характеризует сложность добычи, сформулированы лингвистические правила соответствия ряда характеристик нефти и суммарного коэффициента качества.

Ключевые слова: *нефть, трудноизвлекаемые запасы, функция принадлежности, плотность, вязкость, состав*

QEYRİ SƏLİS KLASTER ANALİZ ƏSASINDA NEFTİN TƏRKİB VƏ XASSƏLƏRİNİN ONUN KEYFİYYƏTİNƏ TƏSİRİNİN TƏHLİLİ

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Xülasə. Təqdim olunmuş məqalədə çətinliklə çıxarılan ehtiyatların təsnifatı və onların keyfiyyətinin qiymətləndirilməsinə dərc olunmuş məlumat araşdırılır və müasir baxışlar ümumiləşdirilir. Son illər ərzində çətinliklə çıxarılan ehtiyatların hasilatı və bu tip karbohidrogenlərin emalının artması müşahidə olunur. Həmin ehtiyatların çıxarılması çətinliyi onların anomal xüsusiyyətləri və mürəkkəb geoloji şəraitlə izah olunur ki, bu da çətinliklə çıxarılan neftin xassələrinin daha dərindən öyrənilməsini əsaslandırır. Məqalədə Qazaxıstanın müxtəlif yataqlarından götürülmüş neft nümunələri üzərində aparılmış tədqiqatların nəticələri, eləcədə qeyri səlis klaster analiz alqoritminin həyata keçirilməsi yolu ilə təsnifatı öz əksini tapmışdır. Təsnifat əlamətləri kimi üç qrup əlamətlər təhlil olunmuşdur. Həmin qruplar aşağıdakılardır: 1) tərkibi xarakterizə edən əlamətlər-bunlar kükürd və xloridlərdir; 2) neftin xassələri-bunlar özlülük və sıxlıqdır; 3) neftin yatım şəraiti-keçiricilikdir. Bununla əlaqədar ilk mərhələdə müvafiq icmal keçirilmişdir. Baxılan təsnifat yanaşmaları mövcud təhlil üsullarının qoyulmuş məsələnin tam surətdə açılmasına imkan vermədiyi və burada müasir üsullardan istifadə olunması vacibliyini göstərdi. Təsnifat ümumiyyətlə qeyri müəyyənlik şəraitində aparılır. Belə ki, müşahidə olunan qeyri müəyyənlik şəraitində həmin şəraiti nəzərə alan üsullardan biri qeyri səlis məntiqə əsaslanan təsnifat üsuludur. Eləcədə məqalədə neftin keyfiyyətini qiymətləndirməyə imkan verən meyar təklif olunmuşdur.Həmin meyar özündə baxılan amilləri cəmləşdirir. Nəticədə üç sinif-klaster alınmışdır ki, bunların hər biri bu və ya digər dərəcədə neftin çıxarılma çətinliyini xarakterizə edir. Qarşılıqlı əlaqə yaradan müvafiq linqvistik qaydalar tərtib olunmuşdur. Həmin qaydalar məlum "əgər...,onda..." prinsipinə əsaslanır və baxılan münasibəti təhlil etməyə imkan verir.

Açar sözlər: *neft, çətinliklə çıxarılan ehtiyatlar, mənsubiyyət funksiyası, sıxlıq, özlülük, tərkib*