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Research trends in Petroleum Engineering Field of Study in 2016–2021 by The Lens data

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Abstract. This article discusses the major trends in Petroleum Engineering research in 2016–2021 based on a bibliometric analysis of metadata of articles indexed by The Lens platform. A comparative analysis of trends in the topics related to Petroleum Engineering is conducted. Major institutes, countries, and funding foundations involved in petroleum engineering research are identified. The leading role of Chinese institutes and foundations in undertaking this research is shown. Links are established between research areas in Petroleum Engineering, Geology and Ecology. Examples of highly cited articles reflecting the main features of publication trends in the field of Petroleum Engineering are given. A cluster analysis of 24,673 titles of articles on the subject of Petroleum Engineering is done, and the names of publications that most reflect the subject matter of each of the 10 identified clusters are presented. A growing interest in the topic of natural gas hydrates over the past four years is noted.

Keywords: Petroleum Engineering, research trends, The Lens, bibliometric analysis, clustering.

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Introduction

Publications on the energy transition focus on renewable energy sources. For example, the article [1] explores the technical and economic characteristics of an accelerated energy transition by 2050 using new data on renewable energy sources. The authors argue that renewable energy can provide two-thirds of the world's total energy demand and contribute significantly to the greenhouse gas emission reductions needed between now and 2050 to limit the rise in the Earth's average surface temperature below 2 °C. A significant amount of research has focused on energy storage. The article [2] provides a comprehensive update on energy storage (ES) technologies, briefly discussing their applications, the barriers to their adoption of ES and their economic feasibility.

The role of hydrocarbon energy sources in the energy transition has received less attention and, moreover, little citation. Such publications maintain that the conventional oil industry has already felt the growing pressures and challenges of the historic energy transition to a low-carbon energy future. The low-carbon strategies of the international oil companies can be divided into three categories, which include a shift toward gas production, direct participation in the low-carbon sector and collaboration with peers [3]. There is another standpoint: the authors of the article [4] try to assess the impact of the problems associated with the energy transition and make a forecast of the development of the Russian oil industry, using the most advanced modeling tools. Their calculations show that even under rather negative scenarios, Russia is able to maintain exports of crude oil and petroleum products at a level above 250 million tonnes of oil equivalent in 2040, remaining the second largest supplier of hydrocarbons in the world.

Given the small number of scientific publications on the petroleum industry during the energy transition, I thought it would be worthwhile to review scientific publications on Petroleum Engineering over the past 6 years to see how the changed context has affected current petroleum engineering research.

Why Petroleum Engineering? On The Lens platform, in the Field of Study taxonomy, which includes the term Petroleum in its title, the Petroleum Engineering category ranks first by the number of indexed documents (see Table 1).

Table 1

Number of papers indexed in The Lens for all years related to Field of Study with the term Petroleum in the title

Field of Study	Number of papers
Petroleum engineering	239,716
Petroleum industry	30,636
Petroleum reservoir	18,122
Petroleum product	13,136
Petroleum ether	12,321
Petroleum coke	4,383
Petroleum geology	4,353
Petroleum exploration	2,996
Petroleum seep	2,418
Petroleum system	1,270
Petroleum production	980
Petroleum geochemistry	762
Petroleum pollution	568
Petroleum oil	512
Petroleum processing	488
Petroleum resin	360
Petroleum chemistry	323
Petroleum microbiology	270
Petroleum naphtha	169

The data in Table 1 demonstrate the predominance of Petroleum Engineering among the Fields of Study.

Given the large number of publications on Petroleum Engineering, the number of bibliometric surveys disclosing trends and topics of publications is extremely low.

Thus, the query “Title: bibliometrics; Filters: Field of Study = (Petroleum Engineering)”, without additional restrictions on time and other filters, gives only 4 Scholarly Works.

And on a query close to bibliometrics: “Title: (“research trends”); Filters: Field of Study = (Petroleum Engineering)” The Lens platform gives 6 Scholarly Works.

To find out if The Lens system is used in the above results, I use the query: “Title: (“research trends” OR bibliometrics) AND (Title: (“The Lens”) OR (Abstract: (“The Lens”) OR Full Text: (“The Lens”)); Filters: Field of Study = (Petroleum Engineering)”, which yields zero results. Thus, out of 239,716 publications related to Field of Study = (Petroleum Engineering), there are no publications related to bibliometrics and research trends analysis using metadata of publications indexed in The Lens.

This provides the motivation for the present bibliometric study on Petroleum Engineering topic using The Lens data.

Next, let us briefly analyze the publications indexed in The Lens related to bibliometrics, research trends and Petroleum engineering, 10 in total.

The poor representation of bibliometric topics in the data obtained by the query “Field of Study = (Petroleum Engineering)” is also reflected in the low citation rate of these papers. Out of 10 publications, only one paper was cited once [5]; the paper is in Korean, which I do not speak, so all I can say is that Gas Hydrate Production is a very hot topic and it is a pity this publication is not in English. The article concerns an analysis of research trends.

Another publication on research trends [6], written in Japanese and entitled “A research trend and future aspects for polymer degradation: A role in the circulation system”, deals with the crucial topic “Polymer Degradation” and “Circulation System”.

The article [7] is written in Korean; the topic of flow behavior and performance characteristics in a multilayer reservoir is noteworthy. The article [8] is also written in Korean.

Papers [9] and [10] are proceedings of the same conference, written in Japanese.

Thus, research trends in Petroleum Engineering are represented by publications in Korean and Japanese. These countries are characterized by high pragmatism in research.

As for the bibliometric studies on the subject we are considering, one of the works is written in Portuguese [11]. In this paper, according to the abstract in English, a bibliometric analysis of the Scopus data on the topic “Two-phase flow in submersible electric pumps” is carried out, and the number of publications in this field of research and the most relevant materials are analyzed. The authors conclude that the main problem is related to multiphase flow with heat exchange in submersible equipment, where different flow patterns can occur.

The second article is in Chinese [12] and uses Thomson Data Analyzer and UCINET to search and quantify articles on oil and gas exploration research from the SCIE database. The result shows that global oil and gas exploration research continues to grow with fluctuations, and this growth is very evident, especially since 1996; reservoir modeling and prediction (hydrocarbon and non-hydrocarbon), seismic exploration and well logging techniques are the priority research areas. This paper is very similar in content to the study I am conducting but deals only with the data up to 2011.

The paper [13] deals with a narrower than Petroleum Engineering but relevant issue “bibliometric analysis of studies published on shale oil”, the review of bibliometric indicators on shale oil was made using data from databases: Web of Science Core Collection (WoS), Journal Citation Reports (JCP), Scopus and SCImago. The data were taken on 2 November 2014. This means that the data for the last 6 years were not considered.

The article [14], written in Chinese and published in 2011, focuses on the papers published in relevant Chinese journals from 2009 to June 2010; the data are analyzed using bibliometric research method. The analysis shows that energy conservation in oil and gas exploration and petrochemical production is a hot topic. The topic under consideration is very relevant, especially considering the fact that the analysis is carried out according to the publications in Chinese journals, but the data are given only for 2009–2010.

Thus, there are very few bibliometric studies on the subject of Petroleum Engineering. They are mostly done for an earlier period than the last 6 years. Much of the research is written in Korean, Japanese and Chinese and focuses on specific but important aspects of Petroleum engineering. The energy transition issues strongly promoted and funded in recent years cannot but influence the research works in the field of Petroleum Engineering, which makes it relevant to conduct a bibliometric study of the publications for the last 6 years (2016–2021).

Materials and methods

This study is based on bibliometric data from The Lens platform related to the Petroleum Engineering Field of Study for the period 2016–2021.

The Lens platform provides open access to the metadata of its indexed publications. At the time of this writing, 243 million scholarly papers are indexed in The Lens. The system provides comprehensive bibliometric analysis capabilities, including the ability to export up to 50,000 records per query. By comparison, Scopus makes it possible to export 2,000 records per query.

As noted in the introduction, there are no bibliometric studies on Petroleum Engineering based on data from The Lens platform for the period 2016–2021.

Below is the rationale for choosing the 2016–2021 interval, based on the claim that the energy transition should inevitably affect publication activity in Petroleum Engineering. This assertion is based on requests to The Lens for a broader interval of 2012–2021.

For this purpose, a series of graphs of 10-year changes in the number of publications for various queries, which have a broader nature than Petroleum Engineering.

Fig. 1 shows a graph of the number of scientific papers published over time by Field of Study = Engineering.

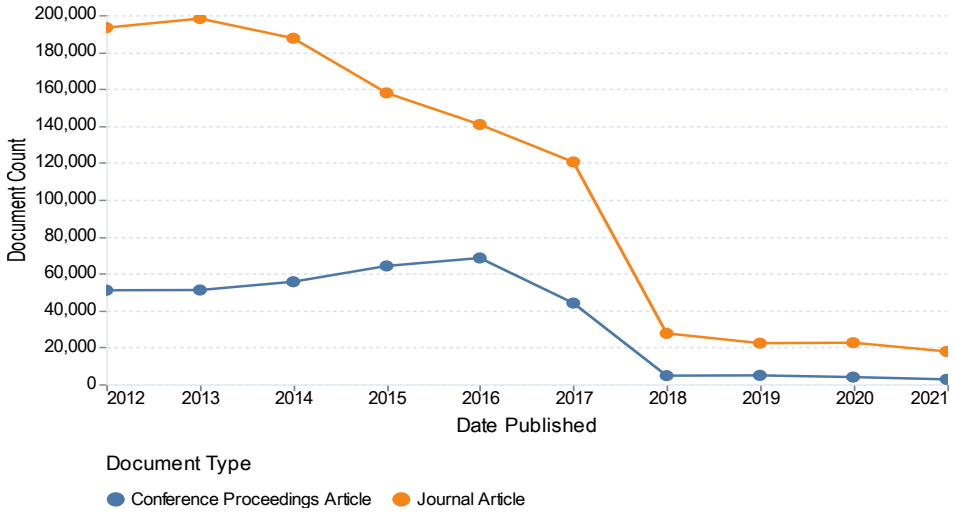

Fig. 1. Scholarly Works over time for Engineering Field of Study for 2012–2021

Fig. 1 shows that the number of conference proceedings decreases sharply in 2016, and the drop in the number of journal articles begins in 2013 and reduces rapidly in 2017.

The Engineering Field of Study is very large and reflects the general decline in attention to engineering in recent years.

To confirm that the general decline in publication activity also affects narrower topics that may be relevant to Petroleum Engineering, I conducted the analysis, the results of which are presented in Fig. 2–3 for the queries “Geotechnical Engineering” and “Engineering Geology” (these are the terms of The Lens taxonomy in the Engineering section).

The results presented in Fig. 2 and 3 agree with the general graph in Fig. 1. Thus, the trend of the decrease in the publication activity in the field of engineering is quite general. At the same time, the decrease in the number of publications on the Field of Study of Petroleum Engineering is less pronounced than the general trend (see Fig. 4).

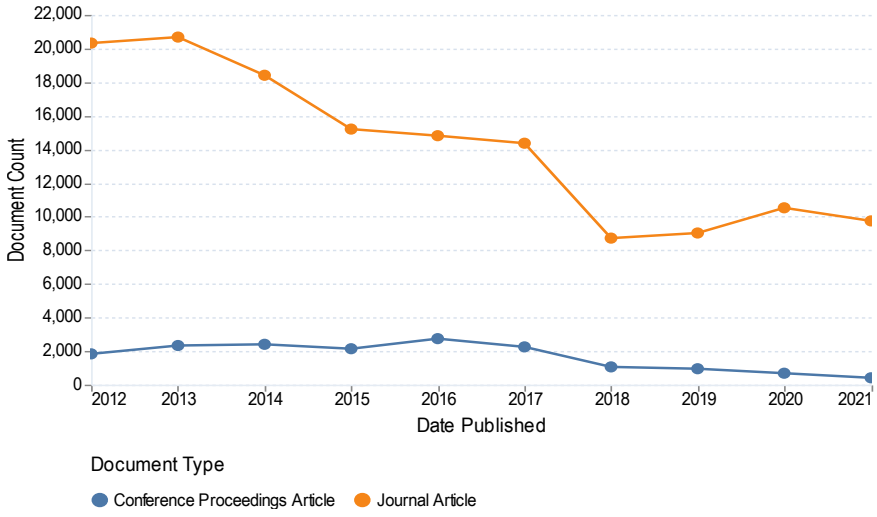

Fig. 2. Scholarly Works over time for Geotechnical Engineering Field of Study

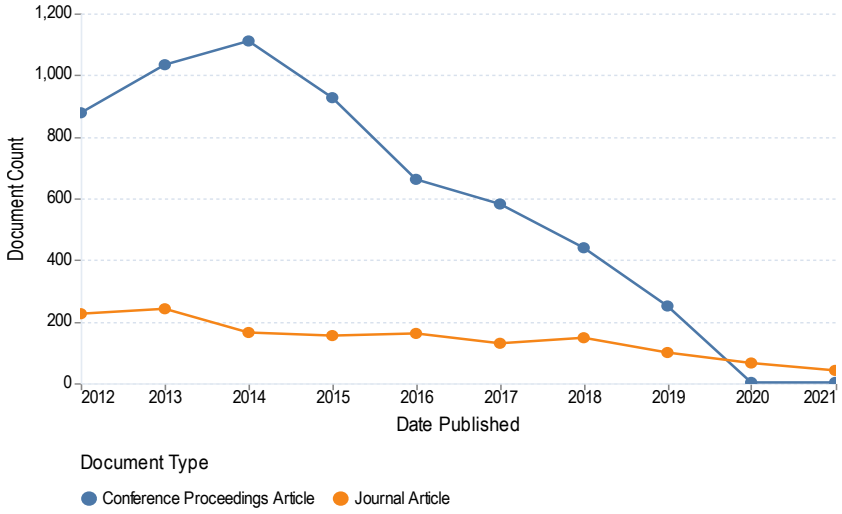

Fig. 3. Scholarly Works over time for Engineering Geology Field of Study

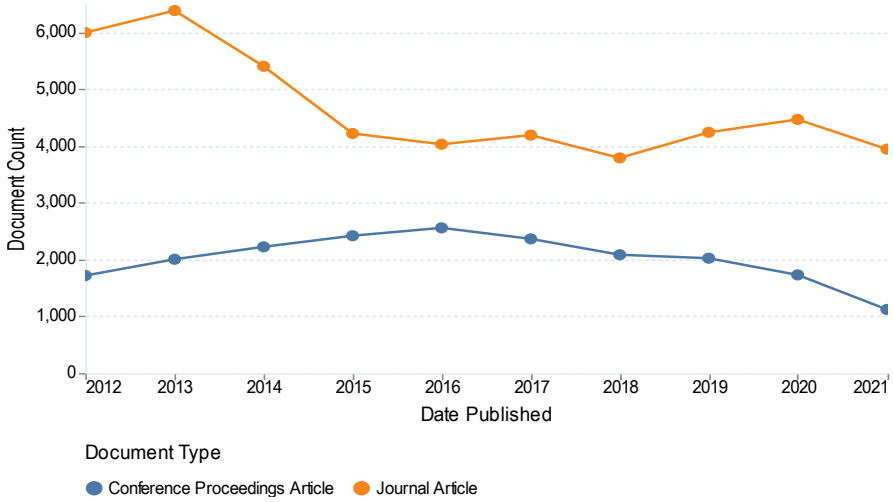

Fig. 4. Scholarly Works over time for Petroleum Engineering Field of Study

Thus, Petroleum Engineering demonstrates not the largest drop compared to preceding Fields of Study.

It should be noted that the change in publication activity around 2016 occurs not only for engineering sciences but also, for example, for the total number of works in economics, as reflected in Fig. 5.

The data given in Fig. 1–5 were the reason to select the period 2016–2021 for further bibliometric analysis of the topic in question.

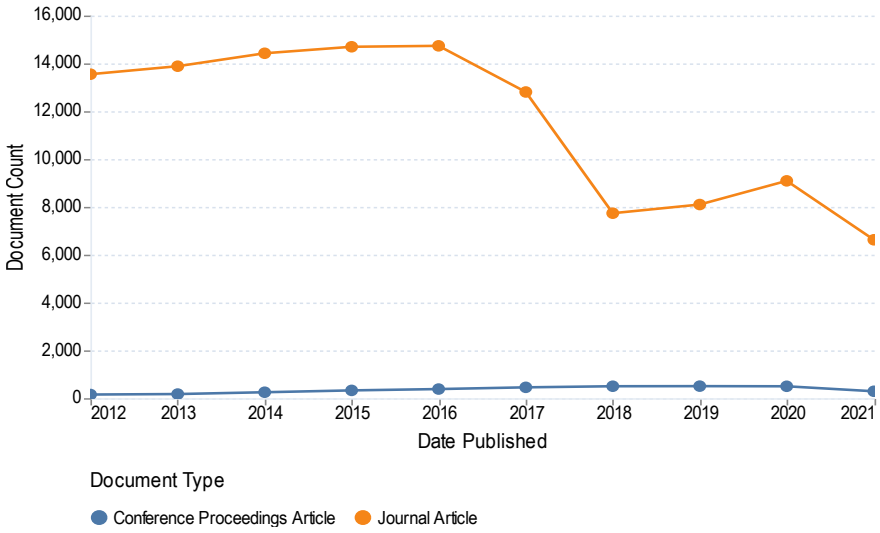

Fig. 5. Scholarly Works over time for Economy Field of Study

But some Fields of Study can grow much faster; for example, if we consider the Digital Economy, then, as Fig. 6 shows, the number of publications on this topic has been growing dramatically over the past 10 years. The same trend is observed for Circular Economy (Fig. 7).

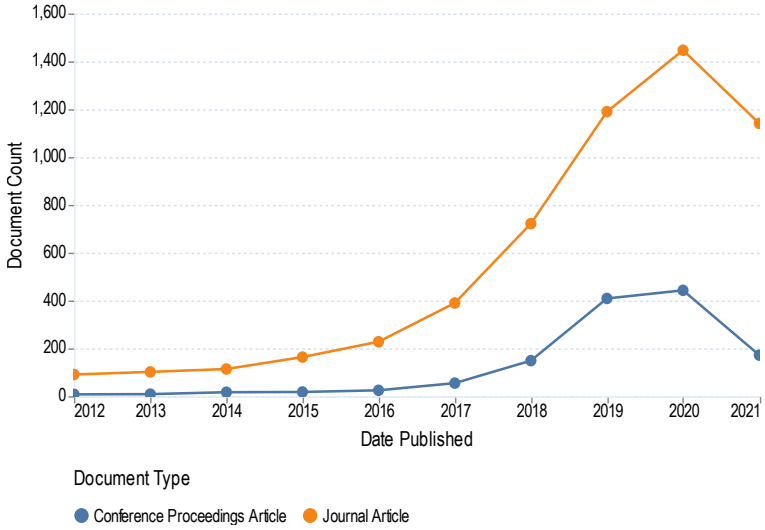

Fig. 6. Scholarly Works over time for Digital Economy Field of Study

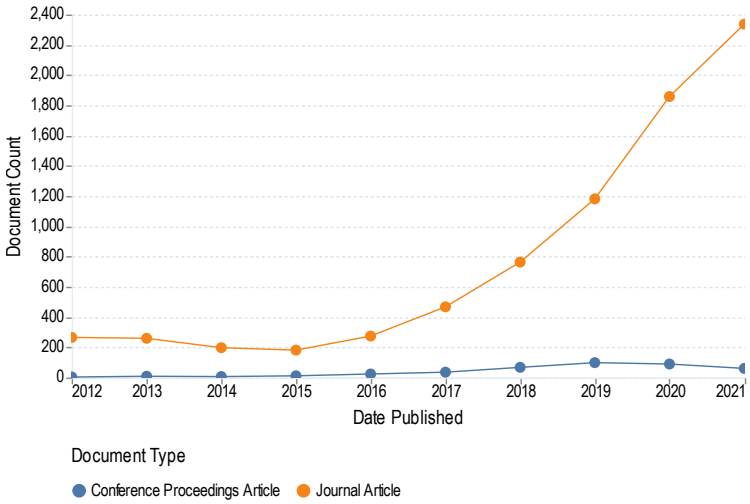

Fig. 7. Scholarly Works over time for Circular Economy Field of Study

Although 2021 is not yet fully indexed, the growth of interest in the topic of Circular Economy is evident. The number of publications has increased almost ten-fold in 10 years, almost as much as on Digital Economy. There have been more conferences on Digital Economy, especially those hosted by businesses.

The Circular Economy is an interesting trend, so more research is needed on how Petroleum Engineering can be incorporated into this process.

The graphs above indicate that over the past 6–7 years there has been a significant shift in the priorities in research areas.

This brief analysis allowed me to formulate a final query to The Lens: Filters: Year Published = (2016–2021); Publication Type = (journal article); Field of Study = (Petroleum Engineering). This query retrieved 24,673 results for Scholarly Works, the metadata for which was exported from The Lens and used for further analysis.

I used the analytical tools of The Lens platform and the Clustering APP that runs on Google Cloud and uses non-negative matrix factorization to perform clustering (Developer: Christoph Mittendorf) [15].

Results of bibliometric analysis of publications in the Petroleum Engineering Field of Study in 2016–2021

In this section, the results of the bibliometric analysis are given as follows: first, the results are presented in the form of a graph or table, followed by brief comments, then examples of several highly cited publications are given with a short summary of their content, which enables a deeper understanding of the results discussed.

Fig. 8 shows the publication activity for 2016–2021 of the 20 universities and organizations with the largest number of publications in the Petroleum Engineering Field of Study.

Petroleum Engineering topics are largely supported by Chinese institutions, including industrial firms PetroChina, Sinopec and CNOOC Limited; North American universities – University of Texas at Austin, Texas A&M University, University of Alberta; Saudi organizations – Islamic Azad University and Saudi Aramco; and the Russian Academy of Sciences. That is, the traditional oil and gas institutions. Yet the dominance of Chinese structures is obvious.

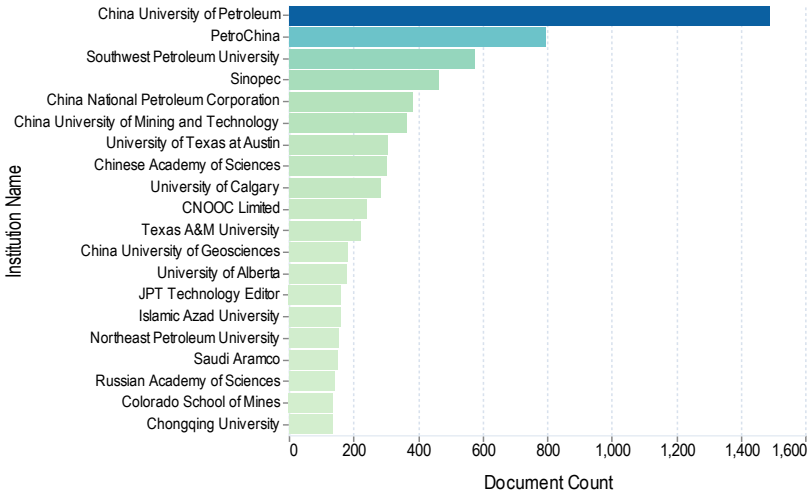

Fig. 8. The Lens Analysis: Top Institution Name by Document Count

The rapid development of the Chinese economy requires an increase in the consumption of energy resources, so China is developing all energy sectors.

Examples of articles with the highest citations for the first two organizations of Fig. 8.

Institution Name: China University of Petroleum

The paper [16] suggests a new model for predicting the thermophysical properties of superheated steam (SHS) in SHS injection wells and for estimating wellbore heat efficiency. The paper presents key recommendations for engineers to optimize injection parameters, as well as estimation of wellbores heat efficiency of SHS injections wells.

In the study [17], the authors propose a new enhanced geothermal system (EGS) with multilateral wells to extract heat from hot dry rock. The results show that the thermal power output, production temperature, heat recovery ratio and stored thermal energy of EGS with multilateral wells are higher than those of conventional EGS with two vertical wells.

Institution Name: PetroChina

Over the past five years, shale gas exploration and development in China has developed in a leap forward way. The article [18] reviews the main achievements in shale gas exploration and development in China and analyzes the development prospects. Offshore shale gas in the Sichuan Basin dominates exploration and development. Commercial production of shale gas from transitional and continental facies is crucial. Low to moderate yield of shale gas wells is the norm in China, so it is very important to develop key exploration and development technologies.

The article [19] estimates recoverable unconventional oil and gas resources worldwide, identifies the main controlling factors and potential regions of rich unconventional oil and gas accumulations, and standardizes the classification of seven resource types (i.e., heavy oil, oil sand, tight oil, oil shale, shale gas, tight gas and coalbed methane). In addition to hot spots in North America, tight oil in the West Siberian Basin and Neuquén Basin and heavy oil in the Arabian Basin will be potential targets for unconventional oil and gas resources in the future.

To show the role of countries in the publication activity on the topic under study, let us present the data as: Institutional country (number of papers) in the Petroleum Engineering Field of Study in 2016–2021 for the top 20 countries: China (5026), United States (2858), Canada (845), Russia (800), Iran (717), United Kingdom (664), Australia (537), India (325), Japan (300), Brazil (286), Germany (285), Netherlands (271), Norway (270), Malaysia (257), Poland (238), Saudi Arabia (210), Republic of Korea (209), Italy (187), Indonesia (167), France (141).

The authors' country affiliation corresponds well with the data in Fig. 8.

For a better understanding of the topics of publications of specific countries, I give examples of the most cited articles for two countries: China and Russia.

China

The article [20] – cited 298 times. In this article, the authors comprehensively analyze research on natural gas hydrates (NGH), which are widespread on the seafloor and in permafrost areas and are considered as an alternative energy to fossil fuels, whose reserves are depleting. Currently, research on NGN exploitation is mainly conducted in three aspects: numerical modeling and analysis, experimental modeling and field testing of various technologies. For commercial NGN operation, risk assessment, economic evaluation and technologies are not sufficiently studied.

The article [21] – cited 249 times. Natural gas hydrates (NGH) are one of the key potential clean energy resources. Its commercial development will help to meet the huge global demand for natural gas and plays a vital role in environmentally sustainable economic growth. Based on nearly two decades of studying reservoir characteristics in the South China Sea (SCS), the China Geological Survey (CGS) conducted its first production test in 2017 at an optimal site selected in the Shenhu area of the SCS. This successful test contributed significantly to the safety control of oil and gas production.

Russia

The article [22] – cited 56 times. The paper presents a mathematical model of gas extraction from a reservoir initially saturated with methane and its hydrate, under conditions of negative (below 0 °C) initial temperature. An algorithm is proposed and a numerical scheme is built to find the main parameters of nonisothermal filtration flow in a water-saturated formation, taking into account the decomposition of hydrate into gas and ice.

The article [23] – cited 54 times. Injection of flue gases or CO_2-N_2 mixtures into gas hydrate reservoirs is considered a promising option for geological storage of CO_2. In this work, a series of experiments were carried out to study the dependence of CO_2 capture efficiency on reservoir conditions. The results showed that more than 60% of the CO_2 in the flue gas was captured and stored as CO_2-hydrate or CO_2-mixed hydrate, producing methane-rich gas. CO_2 capture efficiency depends on reservoir conditions, including temperature, pressure and hydrate saturation.

The cited articles from both countries show a strong interest in research on gas hydrates.

To confirm this, I give the results for the query: (Title: ("gas hydrate") OR (Abstract: ("gas hydrate") OR (Keyword: ("gas hydrate") OR Field of Study: ("gas hydrate")))) Filters: Year Published = (2016–) Publication Type = (journal article) Field of Study = (Petroleum Engineering) according to which there were 63 publications in 2016 and 101 in 2021.

Thus, despite the lack of growth of research in the Petroleum Engineering Field of Study, the interest in research on “gas hydrate” is increasing.

Conducting research requires significant financial investment, so it is useful to consider what funds and how they support research in the Petroleum Engineering Field of Study. Such data are presented in Fig. 9.

This graph shows that Chinese donors actively fund such research and that the number of works supported by them significantly exceeds the number of works funded by the U.S. Department of Energy.

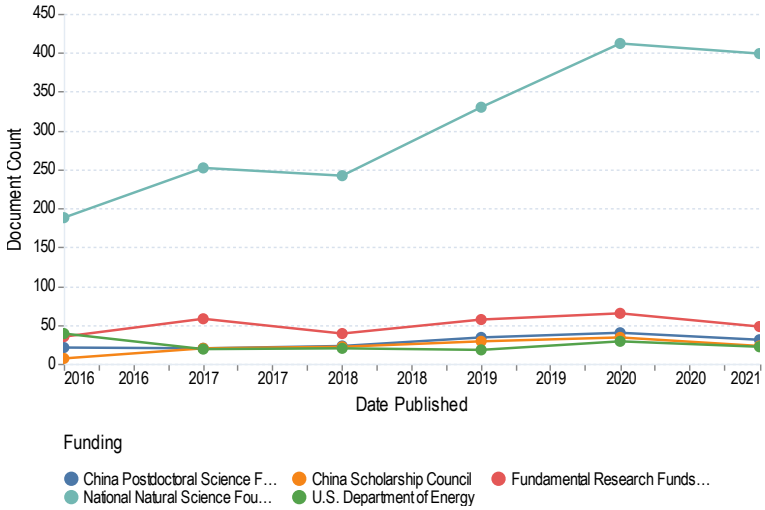

Fig. 9. The Lens Analysis: X—Date Published; Y—Document Count; Colour—Funding

Below are examples of highly cited publications funded by the National Natural Science Foundation of China.

The most cited (298 citations) article has been previously reviewed [20]; the following are:

The article [24] – cited 227 times. Enhanced oil recovery (EOR) techniques have attracted considerable attention worldwide due to the decline in available oil reserves. However, some problems, such as low cleaning efficiency, high cost and potential reservoir damage, still hinder further application of these EOR technologies. This article presents an overview of recent research on the use of nanoparticles for EOR.

The article [25] – cited 222 times. This work performed the first experiments to simulate hydraulic fracturing using supercritical carbon dioxide (SC-CO_2) in shales. Compared to hydraulic fracturing, using SC-CO_2 as the fracturing fluid reduces the pressure required to initiate fractures by more than 50%. This reduction is due to the increased percolation effect and pore pressure with SC-CO_2. The volume of rock fractured by SC-CO_2 is several times greater than hydraulic fracturing, and the fracture surfaces opened by SC-CO_2 are more complex and rugged. SC-CO_2 fracturing is a promising technology for shale gas development because it can effectively solve problems of swelling shale and water scarcity.

Summary of the articles show that the National Natural Science Foundation of China funds innovative research on EOR.

The topics of research are interconnected, so it is reasonable to consider which Fields of Study most often overlap with Petroleum Engineering and which institutes are involved in these studies. The results are given in Fig. 10.

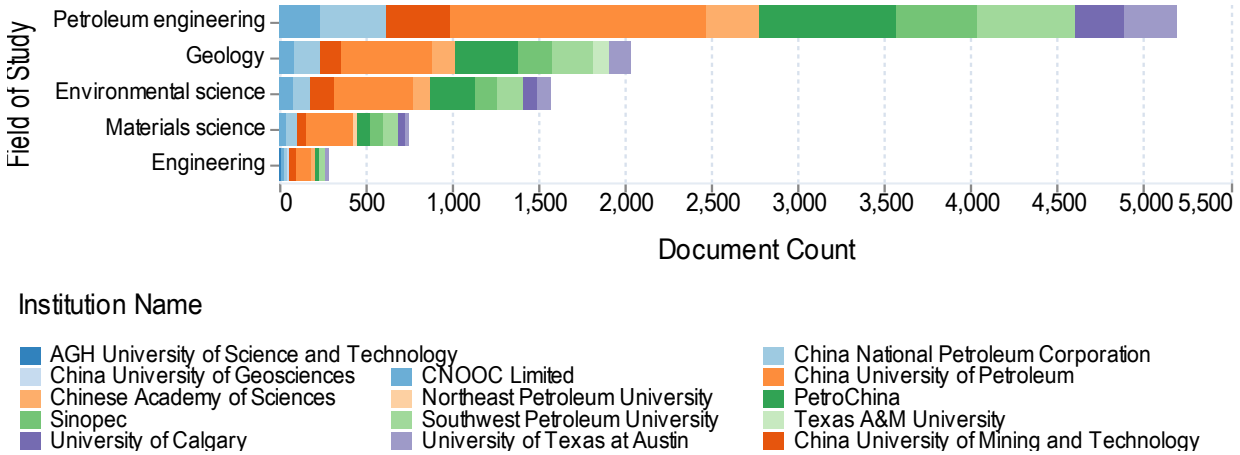

Fig. 10. The Lens Analysis: Fields of Study covered by the most active Institutions

Chinese universities and firms dominate all Fields of Study related to Petroleum Engineering research.

According to Fig. 10, the objectives of Petroleum Engineering are heavily related to Geology, so it is reasonable to give examples of highly cited papers related to both Fields of Study Petroleum Engineering and Geology.

The most cited publication related to Geology [25] has been already mentioned above as funded by the National Natural Science Foundation of China. Such an overlap shows the coherence and sustainability of the reported examples.

The next most cited works are:

The article [26] – cited 209 times. This study presents a detailed review of existing definitions of the brittle index (BI) in rock mechanics, the transition from brittle to ductile and the application of BI to shale fracturing. A combination of laboratory and geophysical methods is recommended for quantifying shale brittleness. Brittleness indices based on elastic moduli and mineral composition are common in field applications and can be obtained both from laboratory studies and from logging data.

The article [27] – cited 175 times. In this article, the authors provided a comprehensive review of the low salinity/engineered water injection techniques (LSWI/EWI) (LSWI/EWI) for both sandstones and carbonates. This article can be used as a guide for starting or implementing LSWI/EWI laboratory and field projects. LSWI/EWI methods have become one of the most important research topics in the oil industry because of their potential benefits for enhanced oil recovery over conventional seawater injection.

As can be seen from the brief description of articles, the most cited works are related to technologies of enhanced oil recovery for different types of reservoirs.

Fig. 10 shows that for the leading institutes the theme “Geology” most often overlaps with the Petroleum Engineering Field of Study, but if we consider the publications of all institutes, such a theme would be “Environmental Science” (see Fig. 11).

One can see here a typical distribution of topics related to Petroleum Engineering. Geothermal gradient seems worth attention to, the topic is not only interesting for traditional energy but also for renewable energy.

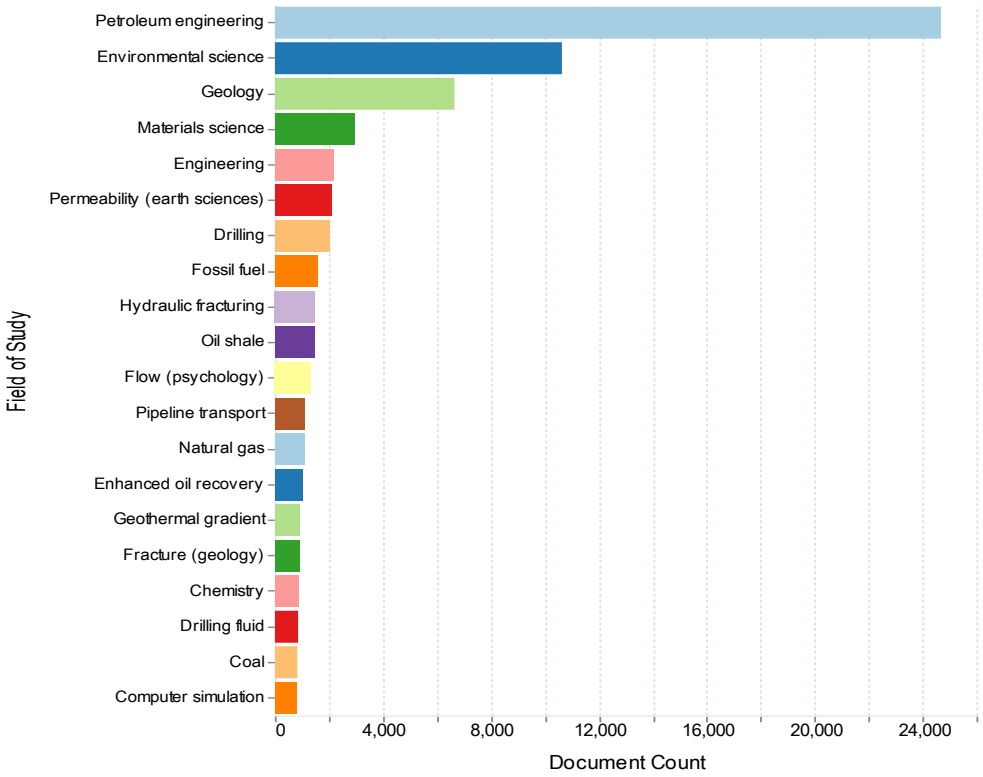

Fig. 11. The Lens Analysis: Top Fields of Study by Document Count

Environmental issues are of significant interest in Petroleum Engineering. Below are the examples of the most cited publications:

The article [28] – cited 224 times. In this paper, the authors conducted a comprehensive review of the literature on enhanced oil recovery (EOR) using CO_2 injection and carbon storage in shale over the past decade. Aspects reviewed include descriptions of major shale oil reservoirs and EOR needs, injection scheme selection, models used to model gas injection, oil recovery mechanisms for different gas types, molecular diffusion and its laboratory measurements, nanopore effects, adsorption effects on carbon storage and transfer, laboratory work on gas injection in shale cores, pilot tests, and economic evaluation. The results of recent pilot tests in the Eagle Ford and Bakken formations were summarized, and finally, economic considerations regarding the feasibility of gas injection into shale oil were presented.

The article [29] – cited 145 times. In this article, the authors first interpret the water return data from a cluster of 18 wells constructed in the Horn River Basin. The authors used numerical modeling to examine the parameters that control water and gas production during formation returns. They concluded that early water and gas production depends on reservoir properties, such as capillary pressure and the complexity of the fracture network created, as well as operational parameters, such as cutoff times. Field data and simulation results show that long cutoff times increase early gas production but reduce load recovery and late gas production, and that only a small fraction of injected water can be recovered during the cleanup phase.

The topics of publications are also well identified by the top keywords, the results are shown in Fig. 12.

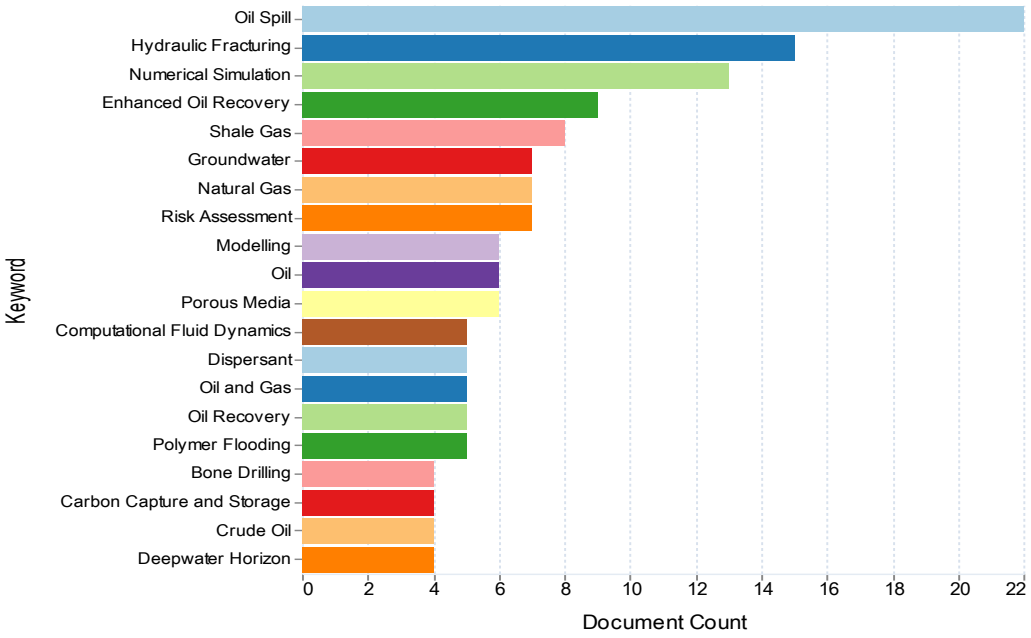

Fig. 12. The Lens Analysis: Top Keyword by Document Count

The increased focus on environmental goals is expressed by the dominance of the keyword “Oil Spill”. Below are examples of the most cited publications:

The article [30] – cited 505 times. In this paper, the authors analyze the problem of increasing the number of accidental oil spills that have a catastrophic impact on the aquatic environment. They suggest that materials with different wettability can be used to remove only one phase from a mixture of oil and water and simultaneously repel the other phase, thus achieving selective separation of oil and water. They show a synergistic effect between surface chemistry and surface architecture that can further promote superwetting, resulting in improved separation efficiency.

The article [31] – cited 122 times. The authors, inspired by the behavior of crossflow filtration in fish gills, propose a crossflow approach through a hydrophilic, sloped gradient membrane to collect spilled oil. In cross-flow, as oil/water flows parallel to the surface of the hydrophilic membrane, the water is gradually filtered through the pores and the oil is repelled, transported, and finally collected for storage. Due to the selective behavior of the water-gated gradient membrane, the large pores in the lower part with high water flow promote rapid water filtration, while the small pores in the upper part with strong oil repulsion allow easy oil transport. In addition, the gradient membrane exhibits excellent antifouling properties due to the protection of the water layer.

In order to explain the trends in the topics of scientific publications, it is useful to present how the number of publications on the main topics evolves over time. Such data are presented in Fig. 13.

Considering research trends by individual Fields of Study, it is noticeable that since 2017 the attention to engineering tasks is decreasing, while the attention to environmental science tasks is increasing. There are no significant changes in other areas of research.

Fig. 14 shows the dynamics of publications as Institution Name by Document Count.

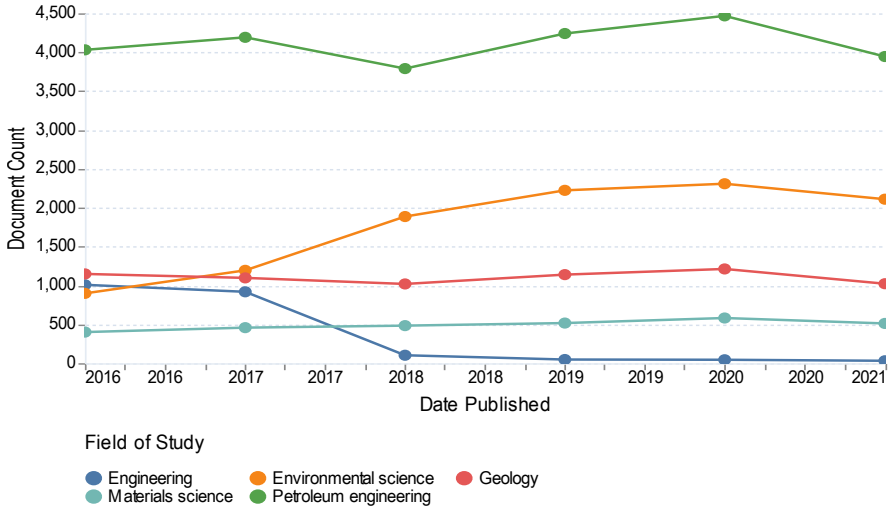

Fig. 13. The Lens Analysis: X—Date Published; Y—Document Count; Colour—Field of Study

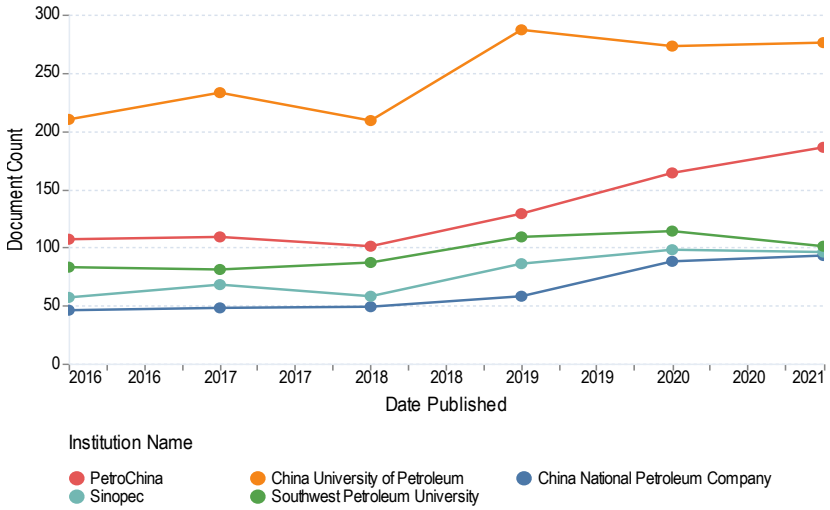

Fig. 14. The Lens Analysis: X—Date Published; Y—Document Count; Colour—Institution Name

Since 2018, China's leading oil and gas companies have been increasing their participation in scientific research. This is not typical for other countries, but the inclusion of industrial firms in scientific research is an advantage for China.

Research topics can be identified by the names of journals and conferences where publications on Petroleum Engineering are posted. Such data are given in Fig. 15.

Conference proceedings play an essential role. Many articles are published in the journal *Neftyanoye Khozyaystvo – Oil Industry*.

The *Journal of Petroleum Science and Engineering* is ranked Q1 in the Engineering, Petroleum category by the JCR, so let's review a few highly cited publications in this journal on the topic discussed in this article.

The most cited articles [26] and [27] published in *Journal of Petroleum Science and Engineering* have been discussed above, so I refer to the following publications as examples:

The article [32] – cited 163 times. The authors review the application of polymer flooding in heavy oil reservoirs.

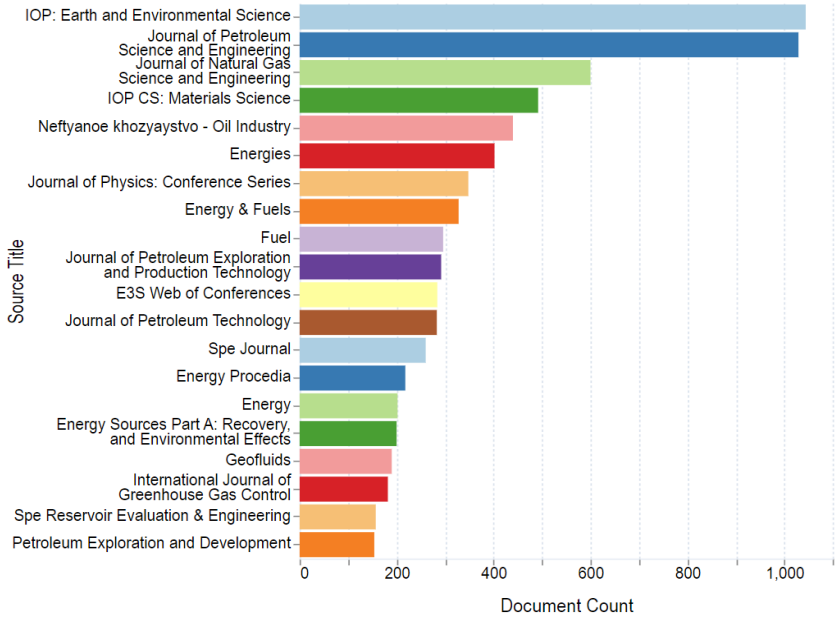

Fig. 15. The Lens Analysis: Source Title by Document Count

The main reasons of its wide use for heavy oil reservoirs in the last two decades were rising oil prices, the extensive use of horizontal wells and advances in polymer technology. This article is a survey of advances and technological trends in polymer flooding in heavy oil reservoirs since the 1960s. The summary results in complete databases of laboratory work, pilot tests and field applications. The database contains qualitative descriptions and quantitative statistics for both research and practical applications. Suitable ranges of crucial reservoir properties and polymer characteristics for successful field applications are suggested.

The article [33] – cited 115 times. The authors performed the first comprehensive review of the current state of experimental studies of foam stabilized by nanoparticles for use in enhanced oil recovery systems. The influence of various critical parameters on foam characteristics was considered. The authors conducted experiments to complement some of the results obtained in the literature. Literature review and experimental results showed that the presence of nanoparticles in appropriate concentration with favorable hydrophobicity improves the static and dynamic stability of foam in porous media. A review of experimental methods showed that the mechanisms of formation, stability, propagation and mobilization of residual oil in porous media are not yet clear on a pore scale due to the limited number of studies. Foams stabilized by nanoparticles for enhanced oil recovery have not found practical application due to limited understanding of the influence of control parameters on foam efficiency and insufficient experimental and modeling studies.

Examples of the most cited articles in *Neftyanoe Khozyaystvo – Oil Industry* journal:

The article [34] – cited 18 times. The authors reviewed the technology of formation of the inverse oil cone below the level of water-oil contact. They propose an analytical method for estimating the time of formation of the inverse oil cone depending on reservoir and fluids properties. On the basis of hydrodynamic modeling, a method of accounting for relative phase permeabilities is proposed. In order to account for the anisotropy coefficient, the hydrodynamic model is used to construct the dependences of oil cone formation time on the anisotropy coefficient for different viscosity ratios of water and oil.

The article [35] – cited 16. The authors proposed a new bottom water shut-off method. It provides for automatic injection of the solution of paraffin in diesel fuel into excess water production zone as water cut increases. This results in the formation of a water barrier (or elimination of water breakthrough problems in the existing barrier) and thus reduction of water cut.

Water-oil contact, hydrodynamic modeling, bottom water shut-off method are the main topics in *Neftyanoe Khozyaystvo – Oil Industry* journal publications.

Clustering of 24,673 article titles on Petroleum Engineering Field of Study

The Lens platform provides significant bibliometric metadata export capabilities, up to 50,000 records. Our query resulted in the export of 24,673 journal article metadata for the 2016–2021 on the Petroleum Engineering Field of Study. Both titles, abstracts and Fields of Study can be used for bibliometric analysis. The advantage of using titles, in my opinion, is that they most expressively reflect the key problem of the article and carry information about the content of the article as a whole; titles often contain some of the key words.

By reading the systematized titles of publications, a specialist can not only get an idea of the dominant topics of publications, but also search both the articles themselves and the similar publications by content. Thus, the clustering of 24,673 article titles on the Petroleum Engineering topic can give a solid reflection of the overall picture of research topics in this field.

To implement this, I use the APP for application developed by Christoph Mittendorf to perform clustering based on non-negative matrix factorization and running on Google Cloud [15].

The results are presented in Table 2, which lists the 10 clusters and the 5 most typical publication titles for each cluster, disclosing its subject matter. Each cluster is described by the 4 terms to which the clustering system assigned the maximum rank.

Table 2

Results of the clustering of 24,673 article titles on Petroleum Engineering Field of Study using the non-negative matrix factorization method

Cluster, keywords	Article titles
1	2
Cluster 1: gas, natural, shale, hydrate	“Investigation into gas production from natural gas hydrate: A review” “Natural gas reservoirs on the oil-gas field Petišovci” “Monkey-wrenching natural gas pipelines” “The role of natural gas hydrate during natural gas transportation” “A prediction method of natural gas hydrate formation in deepwater gas well and its application”
Cluster 2: oil, recovery, enhanced, heavy	“Enhanced oil recovery using biotransformation technique on heavy crude oil” “Performance evaluation of in situ combustion enhanced oil recovery methods for heavy oil recovery” “Study on the oil pipeline design of R oil field” “Simulating the strategies of oil field development for enhanced oil recovery” “A comprehensive review of enhanced oil recovery technologies for shale oil”

Table 2 continued

1	2
Cluster 3: water, flow, injection, high	"From fire to water" "Drilling slowdown sparks water trading" "Physical simulation for water invasion and water control optimization in water drive gas reservoirs" "Optimal operation of the water lifting unit in determining the water flow in the water source" "Hydraulic performance analysis of water supply distribution network using water GEM v8i"
Cluster 4: drilling, fluid, based, fluids	"Drilling with curiosity" "Development of microcalcite-based drilling fluid" "Drilling slowdown sparks water trading" "Drilling-fluid behavior during reservoir-formation drilling and completion" "Data on shale water-based drilling fluid interaction for drilling operation"
Cluster 5: fracturing, hydraulic, shale, fracture	"Should hydraulic fracturing continue" "A review of hydraulic fracturing simulation" "An experimental investigation into the characteristics of hydraulic fracturing and fracture permeability after hydraulic fracturing in granite" "Optimization on fracturing fluid flowback model after hydraulic fracturing in oil well" "Temperature of rock formation and fracturing fluid during the hydraulic fracturing process"
Cluster 6: geothermal, heat, analysis, energy	"Simulation analysis on the heat performance of deep borehole heat exchangers in medium depth geothermal heat pump systems" "Heat transfer analysis of U-type deep borehole heat exchangers of geothermal energy" "Numerical analysis of heat extraction performance of a deep coaxial borehole heat exchanger geothermal system" "Cooling performance of geothermal heat pump using surface water heat exchanger" "Quantification of exploitable shallow geothermal energy by using Borehole Heat Exchanger coupled Ground Source Heat Pump systems"
Cluster 7: reservoirs, permeability, fractured, low	"Evaluation of permeability in fractured carbonate reservoirs by production logging tools (PLT) " "Performance analysis of chemical flooding in fractured shale and tight reservoirs" "Classification evaluation method and its application in low permeability reservoirs" "A new dual-permeability model for naturally fractured reservoirs" "Evaluation of permeability damage caused by drilling and fracturing fluids in tight low permeability sandstone reservoirs"
Cluster 8: wells, horizontal, production, fractured	"Improvement of the efficiency of horizontal wells" "Evolution of production logging in low permeability reservoirs at horizontal wells, multiple-fractured horizontal wells and multilateral wells. Gazprom Neft experience (in Russian)" "Application of combined production logging technology in horizontal wells production composition model of fractured horizontal wells in shale gas reservoirs the problem of a horizontal part cementing of operational horizontal wells"
Cluster 9: reservoir, study, simulation, numerical	"Study on horizontal well fracturing numerical simulation of tight oil reservoir" "Study on the value of a medium reservoir storage capacity (Case study: Karalloe Reservoir)" "Study on the couple of 3D geological model and reservoir numerical simulation results" "Simulation of reservoir operation in a multi reservoir system" "Reservoir simulation study on the permeability jails effect during tight gas production"
Cluster 10: CO_2, storage, injection, recovery	"CO_2 storage potential during CO_2 enhanced oil recovery in sandstone reservoirs" "Water saturated CO_2 injection to improve oil recovery and CO_2 storage" "Prediction of CO_2 saturation by using well logging data in the process of CO_2 EOR and Geological Storage of CO_2" "Compositional modeling of impure CO_2 injection for enhanced oil recovery and CO_2 storage" "Application of CO_2 injection monitoring techniques for CO_2 EOR and associated geologic storage"

It should be emphasized that the presented publication titles most accurately reflect the general subject matter of the cluster according to the terms included in the titles of the 24,673 articles indexed by The Lens platform and related to the Petroleum Engineering Field of Study, these are not the titles of the most cited articles, not the titles of articles in ranking journals. The main sources for The Lens platform until 31 December 2021 were academic.microsoft.com and crossref.org. (Microsoft Academic Website: No longer accessible after 31 December 2021; https://www.microsoft.com/en-us/research/project/academic/articles/microsoft-academic-to-expand-horizons-with-community-driven-approach/).

The results presented above are easily interpreted and require no further discussion, in my opinion.

I believe that the topic of "Natural Gas Hydrate" deserves special attention, both in view of the growing interest in the subject and its multifaceted nature.

Number of journal articles on "Natural Gas Hydrate" in 2016–2021 indexed by The Lens platform in format: Publication Year (Document Count): 2016 (74); 2017 (70); 2018 (103); 2019 (150); 2020 (153); 2021 (202).

Conclusions

The number of Engineering conference papers declines sharply in 2016; the decline in the number of articles begins in 2013 and declines rapidly in 2017.

The Petroleum Engineering category ranks first among the Fields of Study on The Lens platform by the number of indexed papers with the term Petroleum in the title.

Petroleum Engineering does not show the greatest decline compared to other Petroleum studies.

Petroleum engineering topics are mainly supported by Chinese institutions, including industrial companies PetroChina, Sinopec and CNOOC Limited, as well as North American universities – Texas A&M University, University of Alberta; Saudi organizations – Islamic Azad University and Saudi Aramco; and the Russian Academy of Sciences.

Chinese donors actively fund research in Petroleum engineering, and the amount of work they support far exceeds that funded by the U.S. Department of Energy.

Petroleum engineering is strongly linked to geology and environmental research.

Considering research trends in specific areas of Petroleum research, one can notice that since 2017 the attention to engineering tasks is decreasing, and the attention to environmental tasks is increasing. There are no significant changes in other areas of research.

The topic "Natural Gas Hydrate" deserves special attention, both due to the growing interest in it as measured by the number of journal articles in 2016–2021, and due to its multifaceted nature.

Статья написана в рамках выполнения государственного задания (тема «Фундаментальный базис энергоэффективных, ресурсосберегающих и экологически безопасных, инновационных и цифровых технологий поиска, разведки и разработки нефтяных и газовых месторождений, исследование, добыча и освоение традиционных и нетрадиционных запасов и ресурсов нефти и газа; разработка рекомендаций по реализации продукции нефтегазового комплекса в условиях энергоперехода и политики ЕС по декарбонизации энергетики (фундаментальные, поисковые, прикладные, экономические и междисциплинарные исследования)», № 122022800270-0).

References

1. *Gielen D., Boshell F., Saygin D.* et al. The role of renewable energy in the global energy transformation // Energy Strategy Reviews. 2019. Vol. 24. P. 38–50. https://doi.org/10.1016/j.esr.2019.01.006

2. *Gallo A.B., Simões-Moreira J.R., Costa H.K.M.* et al. Energy storage in the energy transition context: A technology review // Renewable and Sustainable Energy Reviews. 2016. Vol. 65. P. 800–822. https://doi.org/10.1016/j.rser.2016.07.028

3. *Peng Y., Li J., Yi J.* International oil companies' low-carbon strategies: confronting the challenges and opportunities of global energy transition // IOP Conference Series: Earth and Environmental Science. 2019. Vol. 237, No. 4. P. 042038. https://doi.org/10.1088/1755-1315/237/4/042038

4. *Kapustin N.O., Grushevenko D.A.* A long-term outlook on Russian oil industry facing internal and external challenges // Oil & Gas Science and Technology – Revue d'IFP Energies nouvelles. 2019. Vol. 74. P. 72. https://doi.org/10.2516/ogst/2019044

5. *Lee J.Y., Lee J., Kim S.* Experimental research trends on gas hydrate production // Korean Society for New and Renewable Energy. 2011. P. 147.2–147.2. https://www.koreascience.kr/article/CFKO201108048136249.page (Accessed on 06.04.2022).

6. *Osawa Z.* A research trend and future aspects for polymer degradation: A role in the circulation system society // Journal of the Japan Society of Colour Material. 2000. Vol. 73, No. 10. P. 504–511. https://doi.org/10.4011/shikizai1937.73.504

7. *Nam S.-G., Park C., Jung S.* Research trends of cross-flow behaviors and production characteristics in a multi-layered reservoir // Journal of the Korean Society of Mineral and Energy Resources Engineers. 2013. Vol. 50, No. 2. P. 306–317. https://doi.org/10.12972/ksmer.2013.50.2.306

8. *Lee S.I., Kang Y.J., Kim D.H.* et al. Basic research trends on labyrinth seal of gas turbine // The KSFM Journal of Fluid Machinery. 2020. Vol. 23, No. 1. P. 32–39. https://doi.org/10.5293/kfma.2020.23.1.032

9. *Tanaka Y.* Research trend of fluid power in JSME Annual Conference 2012 // Journal of the Japan Fluid Power System Society. 2013. Vol. 44, No. 1. P. 34–36. https://ci.nii.ac.jp/naid/10031143387 (Accessed on 06.04.2022).

10. *Ueno S.* Research trends of fluid power in ROBOMEC2013 // Journal of the Japan Fluid Power System Society. 2013. Vol. 44, No. 5. P. 296–297. https://ci.nii.ac.jp/naid/10031194211 (Accessed on 06.04.2022).

11. *de Oliveira F.C., dos Reis M.C., Romero O.J.* et al. Escoamento bifásico em bombas elétricas submersíveis: uma análise bibliométrica // Brazilian Journal of Production Engineering – BJPE. 2021. Vol. 7, No. 3. P. 13–20. https://doi.org/10.47456/bjpe.v7i3.34960

12. *Jidong Z., Junwei Z.* A bibliometrical analysis of oil and gas exploration research // Science Focus. 2013. No. 1. P. 1–7. https://ss.cqvip.com/Qikan/Article/Detail?id=44926402 (Accessed on 06.04.2022).

13. *Lauk K.* Bibliometrical analysis of research published in oil shale // Oil Shale. 2016. Vol. 33, No. 3. P. 290. https://doi.org/10.3176/oil.2016.3.07

14. *Xue Y., Shan N.* A bibliometric research on energy conservation technology theory in petroleum industry // Journal of Southwest Petroleum University (Social Sciences Edition). 2011. No. 05. http://en.cnki.com.cn/Article_en/CJFDTotal-PXSY201105006.htm (Accessed on 06.04.2022).

15. *Mittendorf C.* The Clustering APP — an application that identifies clusters by running topic modelling over your CSV file. https://ml-clustering.ew.r.appspot.com (Accessed on 06.04.2022).

16. *Sun F., Yao Y., Chen M.* et al. Performance analysis of superheated steam injection for heavy oil recovery and modeling of wellbore heat efficiency // Energy. 2017. Vol. 125. P. 795–804. https://doi.org/10.1016/j.energy.2017.02.114

17. *Song X., Shi Y., Li G.* et al. Numerical simulation of heat extraction performance in enhanced geothermal system with multilateral wells // Applied Energy. 2018. Vol. 218. P. 325–337. https://doi.org/10.1016/j.apenergy.2018.02.172

18. *Dong D., Wang Y., Li X.* et al. Breakthrough and prospect of shale gas exploration and development in China // Natural Gas Industry B. 2016. Vol. 3, No. 1. P. 12–26. https://doi.org/10.1016/j.ngib.2016.02.002

19. *Wang H., Ma F., Tong X.* et al. Assessment of global unconventional oil and gas resources // Petroleum Exploration and Development. 2016. Vol. 43, No. 6. P. 925–940. https://doi.org/10.1016/S1876-3804(16)30111-2

20. *Li X.-S., Xu C.-G., Zhang Y.* et al. Investigation into gas production from natural gas hydrate: A review // Applied Energy. 2016. Vol. 172. P. 286–322. https://doi.org/10.1016/j.apenergy.2016.03.101

21. *Li J., Ye J., Qin X.* et al. The first offshore natural gas hydrate production test in South China Sea // China Geology. 2018. Vol. 1, No. 1. P. 5–16. https://doi.org/10.31035/cg2018003

22. *Musakaev N.G., Khasanov M.K., Borodin S.L.* The mathematical model of the gas hydrate deposit development in permafrost // International Journal of Heat and Mass Transfer. 2018. Vol. 118. P. 455–461. https://doi.org/10.1016/j.ijheatmasstransfer.2017.10.127

23. *Hassanpouryouzband A., Yang J., Tohidi B.* et al. CO_2 capture by injection of flue gas or CO_2–N_2 mixtures into hydrate reservoirs: Dependence of CO_2 capture efficiency on gas hydrate Reservoir Conditions // Environmental Science and Technology. 2018. Vol. 52, No. 7. P. 4324–4330. https://doi.org/10.1021/acs.est.7b05784

24. *Sun X., Zhang Y., Chen G.* et al. Application of nanoparticles in enhanced oil recovery: A critical review of recent progress // Energies. 2017. Vol. 10, No 3. P. 345. https://doi.org/10.3390/en10030345

25. *Zhang X., Lu Y., Tang J.* et al. Experimental study on fracture initiation and propagation in shale using supercritical carbon dioxide fracturing // Fuel. 2017. Vol. 190. P. 370–378. https://doi.org/10.1016/j.fuel.2016.10.120

26. *Zhang D., Ranjith P.G., Perera M.S.A.* The brittleness indices used in rock mechanics and their application in shale hydraulic fracturing: A review // Journal of Petroleum Science and Engineering. 2016. Vol. 143. P. 158–170. https://doi.org/10.1016/j.petrol.2016.02.011

27. *Al-Shalabi E.W., Sepehrnoori K.* A comprehensive review of low salinity/engineered water injections and their applications in sandstone and carbonate rocks // Journal of Petroleum Science and Engineering. 2016. Vol. 139. P. 137–161. https://doi.org/10.1016/j.petrol.2015.11.027

28. *Jia B., Tsau J.-S., Barati R.* A review of the current progress of CO_2 injection EOR and carbon storage in shale oil reservoirs // Fuel. 2019. Vol. 236. P. 404–427. https://doi.org/10.1016/j.fuel.2018.08.103

29. *Ghanbari E., Dehghanpour H.* The fate of fracturing water: A field and simulation study // Fuel. 2016. Vol. 163. P. 282–294. https://doi.org/10.1016/j.fuel.2015.09.040

30. *Ma Q., Cheng H., Fane A.G.* et al. Recent development of advanced materials with special wettability for selective oil/water separation // Small. 2016. Vol. 12, No. 16. P. 2186–2202. https://doi.org/10.1002/smll.201503685

31. *Dou Y., Tian D., Sun Z.* et al. Fish gill inspired crossflow for efficient and continuous collection of spilled oil // ACS Nano. 2017. Vol. 11, No. 3. P. 2477–2485. https://doi.org/10.1021/acsnano.6b07918

32. *Saboorian-Jooybari H., Dejam M., Chen Z.* Heavy oil polymer flooding from laboratory core floods to pilot tests and field applications: Half-century studies // Journal of Petroleum Science and Engineering. 2016. Vol. 142. P. 85–100. https://doi.org/10.1016/j.petrol.2016.01.023

33. *Yekeen N., Manan M.A., Idris A.K.* et al. A comprehensive review of experimental studies of nanoparticles-stabilized foam for enhanced oil recovery // Journal of Petroleum Science and Engineering. 2018. Vol. 164. P. 43–74. https://doi.org/10.1016/j.petrol.2018.01.035

34. *Yakupov R.F., Gimazov A.A., Mukhametshin V.Sh., Makaev R.I.* Analytical method for estimating efficiency of oil recovery technology in case of bottom water-drive reservoir, verified on the hydrodynamic model // Neftyanoe Khozyaystvo – Oil Industry. 2018. No. 6. P. 66–69. https://doi.org/10.24887/0028-2448-2018-6-66-69 (In Russ.).

35. *Khisamov R.S., Abdrakhmanov G.S., Kadyrov R.R.* New technology of bottom water shut-off // Neftyanoe Khozyaystvo – Oil Industry. 2017. No. 11. P. 126–128. https://doi.org/10.24887/0028-2448-2017-11-126-128 (In Russ.).

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Исследовательские тренды в области нефтяной инженерии в 2016–2021 гг. по данным реферативной базы The Lens

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Аннотация. В данной статье рассматриваются основные тенденции исследований в области нефтяной инженерии в 2016–2021 гг., выявленные с помощью библиометрического анализа метаданных статей, индексируемых платформой The Lens. Проведен сравнительный анализ тенденций в темах, связанных с нефтяной инженерией. Определены основные институты, страны и финансирующие фонды, участвующие в исследованиях в области нефтяной инженерии. Показана ведущая роль китайских институтов и фондов в проведении таких исследований. Установлена связь между направлениями исследований в области нефтяной инженерии, геологии и экологии. Приведены примеры высокоцитируемых статей, отражающие основные особенности тематик публикаций в области нефтяной инженерии. Проведен кластерный анализ 24673 названий статей по теме «Нефтяная инженерия», представлены названия публикаций, наиболее полно отражающих тематику каждого из 10 выявленных кластеров. Отмечается рост интереса к теме гидратов природного газа за последние четыре года.

Ключевые слова: нефтяная инженерия, исследовательские тренды, The Lens, библиометрический анализ, кластеризация.

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Литература

1. *Gielen D.*, *Boshell F.*, *Saygin D.* et al. The role of renewable energy in the global energy transformation // Energy Strategy Reviews. 2019. Vol. 24. P. 38–50. https://doi.org/10.1016/j.esr.2019.01.006

2. *Gallo A.B.*, *Simões-Moreira J.R.*, *Costa H.K.M.* et al. Energy storage in the energy transition context: A technology review // Renewable and Sustainable Energy Reviews. 2016. Vol. 65. P. 800–822. https://doi.org/10.1016/j.rser.2016.07.028

3. *Peng Y.*, *Li J.*, *Yi J.* International oil companies' low-carbon strategies: confronting the challenges and opportunities of global energy transition // IOP Conference Series: Earth and Environmental Science. 2019. Vol. 237, No. 4. P. 042038. https://doi.org/10.1088/1755-1315/237/4/042038

4. *Kapustin N.O.*, *Grushevenko D.A.* A long-term outlook on Russian oil industry facing internal and external challenges // Oil & Gas Science and Technology – Revue d'IFP Energies nouvelles. 2019. Vol. 74. P. 72. https://doi.org/10.2516/ogst/2019044

5. *Lee J.Y.*, *Lee J.*, *Kim S.* Experimental research trends on gas hydrate production // Korean Society for New and Renewable Energy. 2011. P. 147.2–147.2. https://www.koreascience.kr/article/CFKO201108048136249.page (Дата обращения 06.04.2022).

6. *Osawa Z.* A research trend and future aspects for polymer degradation: A role in the circulation system society // Journal of the Japan Society of Colour Material. 2000. Vol. 73, No. 10. P. 504–511.

https://doi.org/10.4011/shikizai1937.73.504

7. *Nam S.-G., Park C., Jung S.* Research trends of cross-flow behaviors and production characteristics in a multi-layered reservoir // Journal of the Korean Society of Mineral and Energy Resources Engineers. 2013. Vol. 50, No. 2. P. 306–317. https://doi.org/10.12972/ksmer.2013.50.2.306

8. *Lee S.I., Kang Y.J., Kim D.H.* et al. Basic research trends on labyrinth seal of gas turbine // The KSFM Journal of Fluid Machinery. 2020. Vol. 23, No. 1. P. 32–39. https://doi.org/10.5293/kfma.2020.23.1.032

9. *Tanaka Y.* Research trend of fluid power in JSME Annual Conference 2012 // Journal of the Japan Fluid Power System Society. 2013. Vol. 44, No. 1. P. 34–36. https://ci.nii.ac.jp/naid/10031143387 (Дата обращения 06.04.2022).

10. *Ueno S.* Research trends of fluid power in ROBOMEC2013 // Journal of the Japan Fluid Power System Society. 2013. Vol. 44, No. 5. P. 296–297. https://ci.nii.ac.jp/naid/10031194211 (Дата обращения 06.04.2022).

11. *de Oliveira F.C., dos Reis M.C., Romero O.J.* et al. Escoamento bifásico em bombas elétricas submersíveis: uma análise bibliométrica // Brazilian Journal of Production Engineering – BJPE. 2021. Vol. 7, No. 3. P. 13–20. https://doi.org/10.47456/bjpe.v7i3.34960

12. *Jidong Z., Junwei Z.* A bibliometrical analysis of oil and gas exploration research // Science Focus. 2013. No. 1. P. 1–7. https://ss.cqvip.com/Qikan/Article/Detail?id=44926402 (Дата обращения 06.04.2022).

13. *Lauk K.* Bibliometrical analysis of research published in oil shale // Oil Shale. 2016. Vol. 33, No. 3. P. 290. https://doi.org/10.3176/oil.2016.3.07

14. *Xue Y., Shan N.* A bibliometric research on energy conservation technology theory in petroleum industry // Journal of Southwest Petroleum University (Social Sciences Edition). 2011. No. 05. http://en.cnki.com.cn/Article_en/CJFDTotal-PXSY201105006.htm (Дата обращения 06.04.2022).

15. *Mittendorf C.* The Clustering APP — an application that identifies clusters by running topic modelling over your CSV file. https://ml-clustering.ew.r.appspot.com (Дата обращения 06.04.2022).

16. *Sun F., Yao Y., Chen M.* et al. Performance analysis of superheated steam injection for heavy oil recovery and modeling of wellbore heat efficiency // Energy. 2017. Vol. 125. P. 795–804. https://doi.org/10.1016/j.energy.2017.02.114

17. *Song X., Shi Y., Li G.* et al. Numerical simulation of heat extraction performance in enhanced geothermal system with multilateral wells // Applied Energy. 2018. Vol. 218. P. 325–337. https://doi.org/10.1016/j.apenergy.2018.02.172

18. *Dong D., Wang Y., Li X.* et al. Breakthrough and prospect of shale gas exploration and development in China // Natural Gas Industry B. 2016. Vol. 3, No. 1. P. 12–26. https://doi.org/10.1016/j.ngib.2016.02.002

19. *Wang H., Ma F., Tong X.* et al. Assessment of global unconventional oil and gas resources // Petroleum Exploration and Development. 2016. Vol. 43, No. 6. P. 925–940. https://doi.org/10.1016/S1876-3804(16)30111-2

20. *Li X.-S., Xu C.-G., Zhang Y.* et al. Investigation into gas production from natural gas hydrate: A review // Applied Energy. 2016. Vol. 172. P. 286–322. https://doi.org/10.1016/j.apenergy.2016.03.101

21. *Li J., Ye J., Qin X.* et al. The first offshore natural gas hydrate production test in South China Sea // China Geology. 2018. Vol. 1, No. 1. P. 5–16. https://doi.org/10.31035/cg2018003

22. *Musakaev N.G., Khasanov M.K., Borodin S.L.* The mathematical model of the gas hydrate deposit development in permafrost // International Journal of Heat and Mass Transfer. 2018. Vol. 118. P. 455–461. https://doi.org/10.1016/j.ijheatmasstransfer.2017.10.127

23. *Hassanpouryouzband A., Yang J., Tohidi B.* et al. CO_2 capture by injection of flue gas or CO_2 –N_2 mixtures into hydrate reservoirs: Dependence of CO_2 capture efficiency on gas hydrate Reservoir Conditions // Environmental Science and Technology. 2018. Vol. 52, No. 7. P. 4324–4330. https://doi.org/10.1021/acs.est.7b05784

24. *Sun X., Zhang Y., Chen G.* et al. Application of nanoparticles in enhanced oil recovery: A critical review of recent progress // Energies. 2017. Vol. 10, No. 3. P. 345. https://doi.org/10.3390/en10030345

25. *Zhang X., Lu Y., Tang J.* et al. Experimental study on fracture initiation and propagation in shale using supercritical carbon dioxide fracturing // Fuel. 2017. Vol. 190. P. 370–378. https://doi.org/10.1016/j.fuel.2016.10.120

26. *Zhang D., Ranjith P.G., Perera M.S.A.* The brittleness indices used in rock mechanics and their application in shale hydraulic fracturing: A review // Journal of Petroleum Science and Engineering. 2016. Vol. 143. P. 158–170. https://doi.org/10.1016/j.petrol.2016.02.011

27. *Al-Shalabi E.W., Sepehrnoori K.* A comprehensive review of low salinity/engineered water injections and their applications in sandstone and carbonate rocks // Journal of Petroleum Science and Engineering. 2016. Vol. 139. P. 137–161. https://doi.org/10.1016/j.petrol.2015.11.027

28. *Jia B., Tsau J.-S., Barati R.* A review of the current progress of CO_2 injection EOR and carbon storage in shale oil reservoirs // Fuel. 2019. Vol. 236. P. 404–427. https://doi.org/10.1016/j.fuel.2018.08.103

29. *Ghanbari E., Dehghanpour H.* The fate of fracturing water: A field and simulation study // Fuel. 2016. Vol. 163. P. 282–294. https://doi.org/10.1016/j.fuel.2015.09.040

30. *Ma Q., Cheng H., Fane A.G.* et al. Recent development of advanced materials with special wettability for selective oil/water separation // Small. 2016. Vol. 12, No. 16. P. 2186–2202. https://doi.org/10.1002/smll.201503685

31. *Dou Y., Tian D., Sun Z.* et al. Fish gill inspired crossflow for efficient and continuous collection of spilled oil // ACS Nano. 2017. Vol. 11, No. 3. P. 2477–2485. https://doi.org/10.1021/acsnano.6b07918

32. *Saboorian-Jooybari H., Dejam M., Chen Z.* Heavy oil polymer flooding from laboratory core floods to pilot tests and field applications: Half-century studies // Journal of Petroleum Science and Engineering. 2016. Vol. 142. P. 85–100. https://doi.org/10.1016/j.petrol.2016.01.023

33. *Yekeen N., Manan M.A., Idris A.K.* et al. A comprehensive review of experimental studies of nanoparticles-stabilized foam for enhanced oil recovery // Journal of Petroleum Science and Engineering. 2018. Vol. 164. P. 43–74. https://doi.org/10.1016/j.petrol.2018.01.035

34. *Якупов Р.Ф., Гимазов А.А., Мухаметшин В.Ш., Макаев Р.И.* Аналитическая методика оценки эффективности технологии отбора прикровельной нефти из водоплавающих залежей, верифицированная на гидродинамической модели // Нефтяное хозяйство. 2018. № 6. С. 66–69. https://doi.org/10.24887/0028-2448-2018-6-66-69

35. *Хисамов Р.С., Абдрахманов Г.С., Кадыров Р.Р., Мухаметшин В.В.* Технология ограничения притока подошвенных вод в скважинах // Нефтяное хозяйство. 2017. № 11. С. 126–128. https://doi.org/10.24887/0028-2448-2017-11-126-128