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Исследование гидродинамики и массопередачи на высокопроизводительных центробежных тарелках

В статье рассмотрены результаты испытаний высокопроизводительной центробежной тарелки на экспериментальной промышленной установке при ректификации смеси толуол – орто-ксилол под давлением 0,15 МПа. Испытания проводились на двух схемах: с полным возвратом флегмы и в режиме циркуляционного орошения.Анализ экспериментальных данных показал, что производительность центробежной тарелки в 2-3 раза выше, чем у любой барботажной тарелки, эффективность разделения в широком диапазоне нагрузок составляет 90–95 %, интенсивность теплообмена на контактный элемент — от 7000 до 20000 ккал/ч·град. Промышленные испытания центробежных тарелок проведены на установках переработки нефти, в абсорберах очистки природного газа от сероводорода и углекислого газа, на установке производства этилена и подтвердили высокую производительность и эффективность разделения.

Ключевые слова: *центробежная тарелка, турбулентная диффузия, вихревое взаимодействие газа с жидкостью, тепломассообмен.*
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High-Performance Centrifugal Trays Hydrodynamics and Mass Transfer Study

The article discusses the results of testing a high-performance centrifugal tray at an experimental industrial column during the rectification of a toluene-ortho-xylene mixture under a pressure of 0.15 MPa. The tests were carried out on two regimes: full reflux mode and pump around mode. Experimental data analyses showed that the capacity of a centrifugal tray is 2-3 times higher than that of any bubble tray, the separation efficiency in a wide range of loads is 90-95%, the effectiveness of heat transfer on the contact element is from 7000 to 20000 kcal/h·C. Industrial tests of centrifugal trays were carried out at oil refining units, in absorbers for cleaning natural gas from hydrogen sulfide and carbon dioxide, at an ethylene production unit and confirmed high capacity and separation efficiency.

Key words: *centrifugal tray, turbulent diffusion, vortex interaction of gas with liquid, heat and mass transfer.*

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Сравнительная оценка структуры и каталитической активности смешанных оксидов никеля и алюминия

В работе представлены результаты сравнительных исследований текстурных и каталитических свойств смешанных оксидов никеля и алюминия в зависимости от соотношения катионов металлов в растворах при синтезе их предшественников. Структура смешанных оксидов изучалась с помощью рентгеноструктурного анализа, адсорбции-десорбции азота. Показано влияние соотношения катионов никеля и алюминия в смешанных оксидах на их каталитические свойства в процессах крекинга линейных алканов и тяжелой нефти. Показано, что при соотношении Ni^{2+}/A^{3+} 2:1 полученный смешанный оксид обладает наибольшей развитой поверхностью, высокой каталитической активностью в процессах крекинга н-алканов, компонентов тяжелой нефти. Смешанные оксиды Ni-Al обладают каталитической активностью в реакциях изомеризации алканов, что предполагает их использование в качестве носителей катализаторов гидроизодепарафинизации среднедистиллятных углеводородных фракций.
Ключевые слова: *смешанные оксиды никеля и алюминия, рентгеноструктурный анализ, адсорбция-десорбция азота, каталитический крекинг, тяжелая нефть.*
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Comparative Evaluation of the Structure and Catalytic Activity of Mixed Oxides of Ni and Al
The paper presents the results of comparative studies of the textural and catalytic properties of mixed Ni-Al oxides depending on the ratio of metal cations in solutions during the synthesis of their precursors. The structure of the mixed oxides was studied using X-ray structural analysis and nitrogen adsorption-desorption. The effect of the ratio of Ni and Al cations in mixed oxides on their catalytic properties in the cracking of linear alkanes and heavy oil is shown. It is shown that at a Ni^{2+}/A^{3+} ratio of 2:1, the resulting mixed oxide has the largest developed surface, high catalytic activity in the cracking of n-alkanes, components of heavy oil. Mixed Ni-Al oxides have catalytic activity in alkane isomerization reactions, which suggests their use as catalyst carriers for hydroisodewaxing of middle distillate hydrocarbon fractions.
Key words: *mixed oxides Ni-Al, X-ray diffraction analysis, nitrogen adsorption-desorption, catalytic cracking, heavy oil.*

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Каталитическая активность цеолитсодержащей кремнистой породы Татарско-Шатрашанского месторождения: исследование и перспективы применения
В статье представлены результаты исследования цеолитсодержащей породы, проведенные с целью сравнения ее характеристик с промышленным катализатором FCC. В рамках исследования были определены состав и текстурные свойства образцов. Результаты показали, что удельная поверхность природного

алюмосиликата существенно уступает таковой у промышленного катализатора FCC. Экспериментально установлена оптимальная температура для достижения максимальной конверсии н-алканов C_{18}–C_{22}. Определены выходы различных типов углеводородов при варьировании температурных параметров. Обработка природного алюмосиликата соляной кислотой значительно увеличивает количество кислотных центров Бренстеда относительно основных центров Льюиса, что приводит к повышению образования разветвленных алканов и свидетельствует о существенном влиянии кислотной функциональности на реакционную способность катализатора. Полученные данные вносят вклад в понимание физико-химических свойств природных алюмосиликатов и их потенциала в качестве катализаторов для процессов термического облагораживания сверхвязких нефтей.
Ключевые слова: *цеолитсодержащая порода, н-алканы, каталитический крекинг, конверсия, каталитическая активность.*
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Catalytic Activity of Zeolite-Containing Siliceous Rock of the Tatarsko-Shatrashansky Deposit: Research and Application Prospects

The article presents the results of a study of zeolite-containing rock, conducted in order to compare its characteristics with an industrial FCC catalyst. The composition and textural properties of the samples were determined. The results showed that the specific surface area of natural aluminosilicate is significantly inferior to that of the FCC industrial catalyst. The optimal temperature for achieving the maximum conversion of C_{18}-C_{22} n-alkanes has been experimentally established. The yields of various types of hydrocarbons with varying temperature parameters have been studied. Treatment of natural aluminosilicate with hydrochloric acid significantly increases the number of Brensted acid centers relative to the main Lewis centers, which leads to an increase in the formation of branched alkanes and indicates a significant effect of acid functionality on the reactivity of the catalyst. The data obtained make a significant contribution to understanding the physico-chemical properties of natural aluminosilicates and their potential as catalysts for the thermal refining of ultra-viscous oils.
Key words*: zeolite-containing rock, n-alkanes, catalytic cracking, conversion, catalytic activity.*

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Численное моделирование процесса адсорбционной очистки сточных вод от ионов тяжелых металлов

В работе представлено исследование экологически ориентированных технологий адсорбционной очистки сточных вод предприятий топливно-энергетического комплекса, содержащих токсичные ионы тяжелых металлов — мышьяка, меди и цинка. Целью исследования является разработка эффективного и экологически безопасного метода удаления тяжелых металлов с использованием природных цеолитов и создание

численной модели массообмена для прогнозирования параметров процесса. В качестве адсорбента использован модифицированный природный клиноптилолит, отличающийся высокой термической устойчивостью, удельной поверхностью и доступностью. Разработана численная модель массопереноса с учетом внешней и внутренней диффузии. Показано, что при числе Био ≥ 50 и числе Дамкелера 1000 процесс адсорбции протекает эффективно, а определяющим параметром выступает эффективный коэффициент диффузии. Максимальная адсорбционная емкость модифицированного клиноптилолита составила 29,5 мг/г для мышьяка, 34,9 мг/г для меди и 22,7 мг/г для цинка. Результаты позволяют использовать разработанную модель для инженерных расчётов и оптимизации процессов очистки сточных вод предприятий топливно-энергетического комплекса.

Ключевые слова: *топливно-энергетический комплекс, экологическая безопасность, сточные воды, тяжелые металлы, адсорбция, моделирование.*

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Numerical Modeling of Wastewater Treatment by Adsorption of Heavy Metal Ions

The study presents the results of environmentally oriented technologies of adsorption wastewater treatment of enterprises of fuel and energy complexes containing toxic ions of heavy metals — arsenic, copper and zinc. The aim of the study is to develop an effective and environmentally friendly method for the removal of heavy metals using natural zeolites and to create a numerical mass transfer model for predicting process parameters. Modified natural clinoptilolite, characterized by high thermal stability, specific surface area and accessibility, was used as an adsorbent. A numerical model of mass transfer has been developed taking into account external and internal diffusion. It is shown that when the Bio-Bi number is ≥ 50 and the Damkeler Da number is ≈ 1000, the adsorption process proceeds efficiently, and the effective diffusion coefficient Deff is the determining parameter. The maximum adsorption capacity of the modified clinoptilolite was 29.5 mg/g for As, 34.9 mg/g for Cu, and 22.7 mg/g for Zn. The results make it possible to use the developed model for engineering calculations and optimization of wastewater treatment processes at fuel and energy complex enterprises. The use of natural zeolites helps to reduce the anthropogenic load, increase environmental safety and implement the principles of sustainable development in the operation of fuel and energy systems.

Key words*: fuel and energy systems, environmental safety, wastewater, heavy metals, adsorption, modeling.*

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Элементы теории химмотологических процессов

Излагаются отдельные положения и идеи, дающие возможность представить и охарактеризовать совокупность взаимодействующих относительно «простых» физических, химических и физико-химических (элементарных) процессов как идеализированный комплекс «сложных» химмотологических процессов,

протекающих при применении горюче-смазочных материалов (ГСМ) в технике. Рассматриваются возможности, примеры моделирования и обсуждаются закономерности химмотологических процессов в их взаимосвязи с эксплуатационными свойствами ГСМ в химмотологической системе ГСМ – техника – эксплуатация.
Ключевые слова*: горюче-смазочные материалы, химмотологический процесс, эксплуатационное свойство, эксперимент, испытание, моделирование.*
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Elements of the Theory of Chemmotological Processes
Some provisions and ideas that give the opportunity to imagine and characterize the totality of interacting relatively «simple» physical, chemical and physico-chemical (elementary) processes as idealized ensemble of «complex» chemmotological processes that are taking place during the use of POL in equipment are set out. Possibilities, examples of modeling are considered as well as patterns of chemmotological processes are discussed in there interrelation with performance properties of POL in chemmotological system «POL – Equipment – Operating Conditions».
Key words*: fuels, oils and lubricants (POL), chemmotological process, performance property, experiment, testing, modeling.*

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Применение новых карбо- и гетероциклических четвертичных аммонийных солей для снижения испаряемости бензинов
Синтезированы новые четвертичные аммонийные соли, содержащие гем-дихлорциклопропановый и циклоацетальный фрагменты. Приведены результаты исследований присадок, на основе синтезированных соединений, направленные на снижение испаряемости бензинов при хранении в резервуарах. Карбо- и гетероциклические аммонийные соли получены из доступного сырья и не оказывают отрицательного влияния на свойства бензинов.
Ключевые слова*: **автомобильные бензины, четвертичные аммонийные соли, 1,3-диоксациклоалканы,** гем-**дихлорциклопропан.***
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Application of New Carbo- and Heterocyclic Quaternary Ammonium Salts to Reduce the Evaporation of Gasolines

New quaternary ammonium salts containing gem-dichlorocyclopropane and cycloacetal fragments have been synthesized. The results of studies of additives based on synthesized compounds aimed at reducing the evaporation of gasoline during storage in tanks are presented. Carbo- and heterocyclic ammonium salts are obtained from available raw materials and do not adversely affect the properties of gasoline.
Key words*:* *motor gasoline, quaternary ammonium salts, 1,3-dioxacycloalkanes, gem-dichlorocyclopropane.*

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Деаэрирующие свойства огнестойких масел
на основе трет-бутилированных ариловых эфиров ортофосфорной кислоты

Исследована зависимость времени деаэрации от состава огнестойкого масла на основе смешанных фосфатных эфиров фенола и 4-трет-бутилфенола (так называемое трет-бутилированное масло). Время деаэрации определяется соотношением основных компонентов — (трет-бутилфенил)дифенилфосфата (II) и ди(трет-бутилфенил)фенилфосфата (III) — и резко увеличивается с ростом содержания три(трет-бутилфенил)фосфата (IV); трифенилфосфат (I) оказывает минимальное воздействие. Эфиры II–IV выделены в индивидуальном состоянии и охарактеризованы. Показано, что компоненты масла, являясь при комнатной температуре твёрдыми веществами, способны образовывать смеси с температурой застывания минус 17 °С и ниже. Предложена эмпирическая модель, количественно описывающая зависимость времени деаэрации от состава, с учётом которой подобраны составы трет-бутилированных масел, удовлетворяющие по физико-химическим характеристикам отраслевым стандартам России, предъявляемым к огнестойким маслам.

Ключевые слова: *огнестойкое масло, трет-бутилированные арилфосфаты, время деаэрации.*
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Air-Releasing Properties of Flame-Retardant Oils Derived
from Tert-Butylated Aryl Phosphates

The dependence of the air-release time on the composition of a fire-resistant oil based on mixed phosphate esters of phenol and 4-tert-butylphenol (the so-called tert-butylated oil) was investigated. The air-release time is determined by the ratio of the main components – (tert-butylphenyl)diphenyl phosphate (II) and di(tert-butylphenyl)phenylphosphate (III), it increases sharply when the content of tri(tert-butylphenyl)phosphate (IV) increases; the content of triphenylphosphate (I) has minimal effect. Esters II–IV were isolated in individual state and characterized. It has been shown that the oil components, being solid substances at room temperature, are capable of forming mixtures with a pour point of minus 17 °C and below. An empirical model that quantitatively describes the dependence of the air-release time on the composition of the fire-resistant oils is proposed; it allows to choose the compositions of tert-butylated oils satisfying the physico-chemical characteristics of the industry standards of the Russian Federation for fire-resistant oils.

Key words*: fire-resistant oils, tert-butyl arylphosphate, air-release time.*

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Анализ термомеханической стабильности пластичных смазок с разными типами загустителей на основе высокощелочных детергентов

Представлены результаты экспериментальных исследований термомеханической стабильности пластичных смазок с загустителями на основе трех типов высокощелочных детергентов: сульфонатов, алкилсалицилатов и алкилфенолятов кальция с использованием подшипникового стенда. Как было установлено, салицилатные и фенолятные смазки оказались достаточно стабильными к окислению, при этом в случае салицилатов большое влияние также оказывает состав дисперсионной среды.

Ключевые слова*: пластичные смазки, моюще-диспергирующие присадки, антиокислительные присадки, сульфонат кальция, алкилсалицилат кальция, алкилфенолят кальция.*
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Analysis of Thermomechanical Stability of Greases with Different Types of Thickeners Based on Highly Alkaline Detergents

The article presents the results of experimental studies of the thermomechanical stability of greases with thickeners based on three types of highly alkaline detergents: sulfonates, alkyl salicylates and calcium alkylphenolates using a bearing stand. As it was found, salicylate and phenolate lubricants proved to be quite stable to oxidation, while in the case of salicylates, the composition of the dispersion medium also has a great influence.

Key words*: lubricants, detergent-dispersant additives, antioxidant additives, calcium sulfonate, calcium alkyl salicylate, calcium alkylphenolate.*

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Реологическое поведение загущенных водорастворимых базовых масел и пластичных смазок на их основе

Проведено исследование реологических характеристик водорастворимых высокополярных базовых масел с добавкой полимерного загустителя, а также пластичных смазок на их основе. Изучены параметры, определяющие основные эксплуатационные свойства исследованных полиэфирных систем. Установлен ряд ключевых закономерностей реологического поведения этих систем. Показано, что для исследованных

композиций предел прочности, величину эффективной вязкости и реологические свойства определяются концентрацией загустителя и его молярной массой, при этом влияние температуры на предел прочности и величину эффективной вязкости незначительно. Установлено, что с увеличением концентрации загустителя повышается предел прочности смазок. Получен образец с оптимальной концентрацией загустителя, при которой система эффективно сопротивляется деформации сдвига и рассеивает механическую энергию, что проявляется в максимальных значениях предела прочности. Установленные закономерности могут послужить теоретической основой для целенаправленного регулирования реологических характеристик полиэфирных смазочных материалов – как загущенных масел, так и пластичных смазок.
Ключевые слова: *высокополярные смазочные системы, пластичные смазки, диссипативные свойства, полиоксиалкенилполиглицерол, реологические свойства, полиэфиры.*
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Rheological Behavior of Thickened Water-Soluble Base Oils
and Greases Based on Them
The rheological characteristics of water-soluble high-polarity base oils containing a polymer thickener, as well as the grease formulations derived from them, were investigated. The parameters governing the key performance properties of the studied polyester systems were examined. A number of fundamental rheological behavior patterns were identified. It was found that in the tested compositions, the yield stress and viscoplastic properties are primarily determined by the thickener concentration and its molar mass, whereas the influence of temperature on the yield stress is negligible. The study demonstrated that increasing the thickener concentration enhances the structural strength of the system. A sample with an optimum thickener concentration was developed, at which the system exhibits efficient energy dissipation. The established patterns can serve as a theoretical foundation for the targeted adjustment of the rheological properties of polyester-based lubricating materials.
Key words*: high-polarity lubricating systems, greases, dissipative properties, polyoxyalkylene polyglycerol, rheological properties, polyesters.*

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Studying of Deep Coal Seam Characteristics to Predict Their Gas-Bearing Potential
The coal reservoir characteristics are one of key factors controlling coalbed methane (CBM) distribution and enrichment and the CBM development method. Previously, the study of the coal reservoir characteristics in China has been focused on the shallow coal seam (<1500 m), but less attention has been paid to the deep coal reservoir (>1500 m). Thus, the exploration and development of CBM resources is hindered. The CBM exploration and development in the Ordos Basin is concentrated in the coal seam shallower than 800m in the eastern margin and

the coal seam has a high exploration level, but the coal seam deeper than 800m in the Shenmu area is the blank horizon of CBM exploration. The deep coal seam in the Shenmu area is thick and stably distributed. There is lack of understanding of coal reservoir characteristics and gas content in the deep coal seam. This paper aims to investigate the deep CBM at 1755-1764m in the second member of the upper Paleozoic Shanxi Formation (Shan-2 Member) and that at 1815m-1833m in the second member of the upper Paleozoic Taiyuan Formation (Tai-2 Member) with the gas content and other parameters from wireline coring in Well Gu 1. The results show that the Shenmu area has the low-medium rank coal with the high vitrinite content and the medium-high gas-bearing potential. This study provides insight into the gas content of the coal seam deeper than 1500m and establishes a basis for evaluating the 1500m-2000m deep CBM resources within the Ordos Basin.
Keywords: *deep coalbed methane, coal reservoir characteristics, coal seam gas bearing potential, Ordos Basin.*

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Research Progress on Calculation Methods for CO_2 Storage Capacity in Oil and Gas Reservoirs

CO_2 flooding and storage technology is an important approach to achieving the "dual carbon" goals, offering both emission reduction and economic benefits. This paper systematically analyzes the oil displacement and storage mechanism of this technology. Through the research system of comparing the Enhanced Oil Recovery, effective and actual storage capacity, and by using the methodological criticism and model optimization path analysis, it proposes a six-category calculation method system for the Enhanced Oil Recovery storage capacity, and reveals its applicable conditions and technical bottlenecks, providing a scientific paradigm for the construction of a cross-scale storage prediction system. The existing calculation methods are based on the generalized material balance equation to construct the carbon flux conservation relationship, but the static reservoir assumption restricts the multi-mechanism collaborative characterization of heterogeneous reservoirs. The models of structural storage, residual gas storage, dissolution storage and mineral storage have the defects of mechanism separation and parameter idealization, and are only suitable for the pre-evaluation of storage potential. The calculation method for depleted reservoirs only considers structural storage, while water injection development/water invasion reservoirs need to couple dissolution dynamics. The model based on the analogy method, due to its reliance on CO_2-Enhanced Oil Recovery project data, is more suitable for mature development blocks. The effective storage capacity method realizes potential grading through the screening of geological unit storage coefficients, while the actual synchronous storage model introduces the CO_2 oil replacement rate parameter, which can accurately quantify the storage space of low-permeability reservoirs.
Keywords: *storage capacity calculation, storage mechanisms, carbon capture, utilization and storage, enhanced oil recovery mechanisms.*

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A New Method for Inversion of Mineral Abundance on the Moon

The Moon, as the only natural satellite of the Earth, holds significant importance for understanding the history of its formation and evolution through the accurate determination of its surface mineral composition. It also provides a scientific basis for the reasonable development and utilization of lunar resources in the future. This study proposes a new method for lunar mineral abundance inversion. First, the data sources and preprocessing methods are introduced, followed by the establishment of the mineral abundance inversion model. The scientific validity of the new inversion method is verified through experimental implementation. The study shows that the Lunar Mineral Mapper, as a hyperspectral imaging instrument, can reflect the mineral distribution characteristics on the lunar surface. The Apollo mission samples offer reliable ground-truth reference data for quantitative analysis of mineral abundance. The mineralogical analyses of these samples are highly accurate and authoritative. By fusing the mineral composition data from Apollo samples with the remote sensing data of the Lunar Mineral Mapper, the problem of insufficient accuracy in remote sensing data can be effectively mitigated. Sample constraints improve the accuracy and stability of the inversion model. The conclusion is that the new method of mineral abundance inversion based on the fusion of Lunar Mineral Mapper data and Apollo samples is not only a key approach to overcoming the limitations of traditional single data source inversion but also a necessary means to improve the precision of quantitative mineral analysis on the Moon.

Keywords: *lunar mineral mapper data, apollo samples, mineral abundance inversion, new method; model construction.*

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Heavy Oil Steam Injection Boiler Operation Status Intelligent Monitoring and Energy Consumption Optimization Analysis

In the process of heavy oil thermal recovery, the steam injection boiler is one of the most energy-intensive key pieces of equipment. Its operational status directly affects steam quality and injection efficiency. Traditional management methods often rely on manual experience and judgment, which leads to high energy consumption and insufficient steam utilization. To address this problem, this study established an intelligent monitoring system for the operational status of heavy oil steam injection boilers, and developed an energy consumption optimization model. A case study was conducted to verify the advancement of the proposed monitoring and optimization system. The results show that the system can achieve second-level monitoring, accurate evaluation, and efficient early warning. In terms of energy optimization, the unit steam fuel consumption was reduced by about 8–12%, while boiler efficiency improved by 5–7 percentage points. The stability of steam quality and environmental benefits were significantly enhanced. Further economic evaluation indicates annual savings of several million yuan in fuel costs, as well as additional production benefits of tens of millions of yuan, while reducing CO_2 emissions by 20000–30000 tons. The conclusion confirms that the intelligent monitoring and optimization system for heavy oil steam

injection boilers has important significance in promoting energy conservation, emission reduction, and green development in the oil and gas industry.

Keywords: *heavy oil, steam injection boiler, operational status, intelligent monitoring, energy consumption optimization.*

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Research on Collaborative Optimization Method of Well Pattern Adjustment and Formation System Subdivision in Ultra-High Water Cut Reservoirs

Most reservoirs still use traditional formation division methods, failing to dynamically subdivide oil layers based on detailed geological studies. This results in low utilization rates of high-quality reservoirs and wastage of injection and production resources in inefficient layers. Addressing this issue, this research analyzes the theory of well pattern adjustment optimization for ultra-high water cut reservoirs and introduces a collaborative optimization method for tomographic subdivision and well pattern adjustment. On this basis, using a specific oilfield as an example, case application and effect analysis are carried out to lay the foundation for improving the development efficiency and effectiveness of ultra-high water cut reservoirs in China. Research shows: Formation subdivision based on fluid unit concepts can significantly improve reservoir utilization. The constructed multi-objective optimization mathematical model effectively describes the coupling relationship between formation systems and well patterns. After applying the collaborative optimization measures of well pattern adjustment and formation subdivision in a specific oilfield, the formation utilization rate increased to 91%, and the expected ultimate recovery rate improved by 7.2%, with a collaborative synergy contribution rate of 28.3%, confirming the systematic advantages of collaborative optimization. The conclusion suggests that this method can provide technical support for domestic ultra-high water cut oilfields to improve recovery rates and extend stable production periods.

Keywords: *ultra-high water cut, reservoir well pattern adjustment, formation subdivision, collaborative optimization, effect analysis.*

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Digital Modeling of Bridging and Plugging Dynamics in Fractures and Leakage Control in Fractured Strata

Fractures are important seepage channels in oil and gas extraction and are the key to efficient resource exploitation. However, with the extensive development of fractures, they have also become the main cause of severe drilling fluid and oil and gas leakage. In order to enhance the leakage control of fractured strata, the plugging mechanism was studied through the computational fluid dynamics - discrete element method (CFD-DEM) numerical simulation. This paper focused on the spherical particle diameter, concentration dose, gradation, fluid density and velocity. The research found that for monodisperse particles, under the condition of R=0.4, the best blocking efficiency can be achieved through sequential double-particle bridging. A concentration of 15% was determined to be the most effective dose. When mixed particle sizes form multi-level sealing layers, they can adapt to different fracturing conditions. In addition, the particle transport mechanics in the crack was controlled by the fluid density. When the density range of particles was between 1.80 and 2.20 g/cm^3, the probability of retention in the crack was high and the formed leak-stopping layer was the longest. In this study, the best leak-stopping effect was achieved at a speed of 0.8 m/s by minimizing the migration velocity and maximizing the sealing integrity. Ultimately, the results indicated that particle size, concentration and gradation were the key factors affecting the effectiveness of plugging.

Keywords: *fractured reservoir, particle plugging, numerical simulation, CFD-DEM, fluid.*

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Research Method and Application of Source-Fault-Cap Coupling Oil and Gas Migration to Overlying Reservoir Distribution

Based on the study of the migration mechanism and form distribution of the source-fault-cap coupling oil and gas to the overlying reservoir, the source-fault coupling oil and gas migration parts of different types of sources are determined by using the oil and gas supply parts of different types of sources and the fracture migration parts. Using the relative thickness of ancient fault of mudstone caprock, the distribution position of fault-cap coupling oil and gas migration form is determined. The superposition of the two has established a set of research methods for the distribution of source-fault-cap coupling oil and gas migration to the overlying reservoir. It is used to study the distribution of oil and gas migration from the source rock of the third member of the Shahejie Formation (Es_3), the Nandagang fault and the mudstone caprock of the middle sub-member of the first member of Shahejie Formation(Es_1^z) to the third member of the Dongying Formation(Ed_2) in the Qikou Sag of the Bohai Bay Basin. The results show that there are four types of oil and gas migration from the source rock of Es_3, the Nandagang fault and the mudstone

caprock of E_{s1}^{z} to Ed_2. It shows that this method is feasible to study the distribution of source-fault-cap coupling oil and gas migration to overlying reservoirs.
Keywords: *source-fault-caprock matching; hydrocarbon migration form; distribution location; research method.*

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Evaluation Model and Application of Remaining Oil Potential
Based on Combined Weight Method

In response to the issue of excessive reliance on subjective experience in determining indicator weights for remaining oil potential evaluation in high-water-cut oilfields, an evaluation model based on the combined weighting method and fuzzy comprehensive evaluation was developed. Appropriate evaluation indicators were selected by comprehensively considering remaining oil reserves and ease of extraction. The Analytic Hierarchy Process and entropy weight method were employed to calculate subjective and objective weights, respectively, and a fuzzy comprehensive evaluation model was established to assess remaining oil potential. Taking actual production blocks in the oilfield as the research subject, the evaluation results indicate that the overall potential of remaining oil in the production blocks is relatively limited. Multiple layers require further potential tapping through measures such as optimizing injection-production patterns, implementing refined water flooding, or applying tertiary oil recovery techniques. This evaluation model effectively reduces subjectivity in weight assignment, enhances the reliability of the evaluation results, and provides a scientific basis for assessing remaining oil potential and formulating corresponding extraction strategies.
Keywords: *remaining oil, analytic hierarchy process (AHP), entropy weight method, combined weighting, fuzzy comprehensive evaluation.*

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Oil Import Demand Forecasting based on Machine Learning Technology under Energy Transformation Background

Oil demand forecasting is an essential national energy security and economic development issue. With the acceleration of global energy transformation, countries gradually replace traditional energy with new energy to ensure a safe and stable national energy supply. This paper intends to explore the impact of the increase in the supply of new energy, such as wind energy, solar energy, hydropower, and nuclear energy, on the demand for oil imports in the context of energy transformation. Through the analysis of the relationship between the alternation of new and old energy, and the collection of China's statistical yearbook data, the combination of key indicators is determined using the grey correlation method and machine learning method. A prediction method for oil import demand with the highest prediction accuracy and stability is proposed through the comparative experiments of different models.

Keywords: *energy transformation, oil demand, forecast, machine learning.*

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Analysis of New Technologies for Corrosion Monitoring and Protection of Gas Pipelines

Corrosion is a major factor threatening the operational safety of gas pipelines. To assess pipeline corrosion rates, this study introduces intelligent resistance probe technology, providing a systematic overview of its principles and components. Additionally, nano-composite coating materials are introduced to explore this novel protection technology. Finally, an integrated study on the application of intelligent monitoring and nano-protection technologies is conducted to lay the foundation for ensuring the safe operation of gas pipelines. The research results indicate that intelligent resistance probe technology enables real-time monitoring of gas pipeline corrosion rates. Pipeline corrosion risk assessment is based on accurate corrosion rate measurements, combined with pipeline operational parameters and environmental factors, to comprehensively determine whether severe corrosion risks exist. Compared with traditional anti-corrosion coatings, nano-composite coatings exhibit significant technological advantages, including enhanced protective performance, extended service life, excellent wear resistance, and superior environmental adaptability. These characteristics make them an ideal choice for long-term corrosion protection of gas pipelines, particularly in harsh environments such as acidic soils and microbial corrosion.

Keywords: *gas pipeline, corrosion monitoring, intelligent resistance probe technology, new protection technology, nano-composite coating.*

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Experimental Study on the Influence of Drilling Fluids on the Rock Mechanics of Shale

This study takes the shale of the Jurassic Da'anzhai Member in the Sichuan Basin as the research object. The mineral composition, microstructure and physicochemical properties of the shale were systematically analyzed via X-ray diffraction, scanning electron microscopy, basic physical property testing, rolling recovery tests, linear expansion rate tests, wettability tests and triaxial mechanical experiments. The results indicate that the shale has a high clay minerals content (average of 58.52%), which is mainly composed of illite and chlorite. It is characterized by well-developed microfractures, strong oil wettability and easy hydration when in contact with water. After soaking in the JFS water-based drilling fluid, the compressive strength and elastic modulus of the core decrease significantly, with the reduction rates reaching 43.1% and 50.3%, respectively. The mechanical properties further deteriorate as the soaking pressure (1-7 MPa) increases and the soaking time (1-15 days) increases. By optimizing the drilling fluid system, it was found that adding 50% organic salt inhibitor effectively alleviated the strength weakening. Compared with those of the unoptimized system, the compressive strength and elastic modulus increase by 14% and 16.2%, respectively. These findings provide a theoretical basis and technical support for the selection of drilling fluids and the maintenance of wellbore stability in the Da'anzhai Member shale formation.

Keywords: *Da'anzhai, rock mechanics, drilling fluid, strength characteristics.*

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Controlling Bottom-Water Coning Using a Degradable Temporary Barrier during Plugging and Conductivity Loss after Hydraulic Fracturing

$CAPM_5$, a newly developed degradable sinking agent, shows promise in forming effective barriers to control fracture height without damaging the reservoir. Laboratory experiments were conducted to evaluate the plugging and removal abilities of $CAPM_5$. These experiments simulated the deployment and compaction of the sinking agent within fractures and tested the conductivity of closed fractures post-degradation and post-acid etching. The results indicate that $CAPM_5$ forms effective barriers with significant pressure-bearing capacities in both initial and stable states. Initial barriers in steel cores showed a decrease in pressure-bearing capacity with increasing fracture

width, whereas stable barriers in carbonate cores exhibited increased pressure-bearing capacity with wider fractures. According to the net pressure during the acid fracturing process of the carbonate reservoir in the Gaoshiti gas field, which is approximately 5-7MPa, effective barrier is predicted to form at a fracture width of 2-4 mm at the fracture's bottom. Furthermore, fractures subjected to residual acid etching displayed a significant decrease in conductivity with increasing closure stress, however a minimal level of conductivity remained. Non-etched fractures showed significantly lower conductivity compared to etched ones under the same stress conditions, and high closure stress resulted in almost complete loss of conductivity, effectively isolating bottom water and preventing high water production. In conclusion, the degradable sinking agent $CAPM_5$ demonstrates substantial pressure-bearing capacity and effective barrier formation during acid fracturing operations. Following degradation, $CAPM_5$ minimizes reservoir damage and effectively isolates bottom water, offering a promising solution for managing deep carbonate reservoirs.

Keywords: *acid fracturing, degradable sinking agent, fracture height control, bottom-water, fracture conductivity.*

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Enhancing Microfracture Conductivity in Gas Shale Using Micro-Proppants

The simulated hydraulic fracturing experiments revealed that microfractures accounted for a relatively high fracture surface density, approximately two-thirds of the total fracture surface area, with an average fracture width of 0.245 mm. These microfractures constitute a critical component of the volumetric fracture network that develops in shale gas wells after hydraulic fracturing. The fracture conductivity tests under unsupported conditions indicated that both shear-slip and open-type microfractures exhibited limited conductivity under high closure stress, falling short of the optimal level required for effective gas-well stimulation. This observation was consistent with the rapid decline in post-fracturing production and confirmed that the low long-term conductivity of microfracture systems constrains the gas-supply capacity of wells. To address this limitation, the use of fine-grained proppants (typically < 300 μm) was proposed to mitigate the stress sensitivity of microfractures, reduce mechanical damage, and enhance fracture conductivity. Experimental results demonstrated that micro-proppants effectively preserved microfracture conductivity under high closure stress; however, the conductivity was highly dependent on proppant concentration. An optimal placement concentration was identified, reflecting the transition in the dominant role of micro-proppants within microfractures, from propping at low concentrations to plugging when excessive. Excessive proppant loadings increased fracture spacing but reduced the effective seepage area, leading to diminished flow capacity. Consequently, an optimal micro-proppant placement concentration was determined to ensure the

long-term retention of high conductivity. In this study, the optimal value was 0.078 kg/m2 for microfractures with an average width of 0.261 mm under high closure stress. These findings provide valuable guidance for optimizing proppant design and enhancing fracture reconstruction efficiency in shale gas reservoirs.
Keywords: *gas shale, induced microfracture, microproppant, conductivity, placement concentration.*

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Foam Stability and Its Microscopic Response Behavior

Foam stability is a critical factor influencing the drainage efficiency of foam-assisted deliquification in deep coalbed methane (CBM) reservoirs. This study investigated the macro- and micro-scale stability characteristics of two foam drainage agents from a deep CBM block in China. The effects of four key parameters on macro-stability performance were investigated using static evaluation methods, including -salinity, temperature, pH, and concentration. Simultaneously, polarized light microscopy was employed to characterize microstructural features including bubble morphology, population density and size distribution, thereby elucidating the dynamic macro-micro interactions. The results demonstrated that the high-salinity conditions prevalent in deep CBM development significantly alter the interfacial tension of foam drainage agents. Experimental quantification revealed the sensitivity hierarchy of parameters affecting the drainage half-life as follows: salinity > temperature > pH > foam drainage agent concentration. Microstructural analysis showed that bubble coarsening rates were effectively suppressed under low-temperature and neutral-pH conditions, while exhibiting accelerated growth kinetics in high-temperature, high-salinity environments, leading to compromised foam stability. Although generally consistent with macroscopic trends, certain operational regimes displayed divergent macro-micro behaviors, highlighting the necessity of multiscale investigation approaches. The established macro-micro correlations provide fundamental insights for optimizing foam-assisted deliquification operations and developing targeted defoaming strategies in deep CBM reservoirs, offering both theoretical guidance and practical significance for field applications.
Keywords: *foam drainage agent, foam stability, governing factors, liquid drainage rate, microscopic characterization.*

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Research on Descaling and Decongestion Technology
of Ground Gathering and Transportation System

In this paper, for the scaling phenomenon in the gathering and transmission system of Block A, combined with on-site research, scale sample collection and water quality experiments, we systematically analyzed the types, causes and main influencing factors of scaling, and made it clear that the scaling is mainly calcium carbonate, accompanied by a certain amount of magnesium carbonate and silicate scale, and its formation is closely related to the pH value, temperature, ionic composition and time. Aiming at the problems of fast reaction speed, uneven cleaning and secondary deposition in the practical application of traditional descaling technology, the study introduces foam acid descaling technology, and systematically carries out the evaluation of scale dissolving performance, retardation performance, oil washing ability, suspension ability and corrosion inhibition performance of foam acid, and the experimental results show that the foam acid system has a significant advantage in the high efficiency of descaling, prolonging the reaction time, reducing the damage of corrosion, and removing the organic inclusions. Through the on-site application of two test wells, the foam acid descaling operation effectively removed 7-9mm thickness of scale in the tubing, significantly reduced the wellhead backpressure to normal level, and the success rate and effect of the construction reached 100%. The study shows that the foam acid descaling technology is suitable for the complex working conditions of high temperature, high mineralization and high oil content of scale samples in M Oilfield, and has good prospects for promotion. Finally, the article suggests that it is necessary to further promote the intelligent monitoring and predictive anti-scaling technology of the gathering and transportation system, so as to promote the development of oilfield gathering and transportation system in the direction of green, high efficiency and intelligentization.

Keywords: *scaling mechanism, descaling efficiency, corrosion inhibition performance, descaling and unblocking.*

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A High-Accuracy Gaussian Process Regression Model
for Gas Flow State in Compressor Stations Based on Simulation Data

This study proposes an improved Gaussian Process Regression (GPR) model for accurate pressure prediction within the compressor station. First, due to the limited operating conditions available from the data source of station, a steady-state compressor station simulation model is constructed for high-quality training dataset generation. Subsequently, the Latin Hypercube Sampling (LHS) is used to generate simulation data encompassing a wide range of operating conditions. Furthermore, an adaptive sampling method is employed to accurately select samples in the regions with multiple local extrema that significantly influences model accuracy. In addition,

informed by physical mechanics, a hybrid kernel structure is designed to enhance nonlinear fitting ability of GPR model. The proposed GPR model is validated on both simulated and actual station data, demonstrating superior accuracy over basic data-driven models. Moreover, the data-driven approach drastically improves computational efficiency.
Keywords: *compressor station monitoring, gaussian process regression, hybrid kernels, adaptive sampling.*

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Some approaches for Heavy Oil Displacement Compound Development
Based on Internet of Things Monitoring Data

Heavy oil displacement compound development involves drastic changes in formation temperature and seepage conditions. Traditional methods relying on manual monitoring and empirical judgment are often delayed, making it difficult to timely reflect dynamic development performance. To address this problem, this study establishes an evaluation and early warning system for heavy oil displacement compound development based on Internet of Things (IoT) monitoring data. The study first introduces the system design and methodology, then discusses the system architecture and implementation, and finally conducts case studies and application validation, laying a foundation for improving the effectiveness of heavy oil displacement compound development. Research results show that, through application verification in a typical heavy oil field, the system achieves closed-loop operation from monitoring and evaluation to early warning and decision-making. It significantly improves production efficiency, reduces unit energy consumption and CO_2 emissions, and enhances safety response capability. The conclusion indicates that the system has good feasibility and promotion value, and can provide technical support for the digital, intelligent, and green transformation of heavy oil development.
Keywords: *internet of things, monitoring data, heavy oil displacement compound development, effect evaluation, early warning system.*

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Sweet-Spot Evaluation in a Highly Heterogeneous Tight Sandstone Gas Reservoir

The efficient development of tight sandstone gas reservoirs is severely challenged by profound heterogeneity, which leads to complex pore structures and highly variable permeability, making sweet-spot prediction extremely difficult. Traditional porosity-permeability models often fail in such reservoirs. This study proposes a novel workflow that integrates the hydraulic flow unit (HFU) concept with the XGBoost machine learning algorithm to accurately characterize and predict sweet-spots in the Shaximiao Formation (J_2s) of the ZT Gas Field, Sichuan Basin. First, four distinct HFUs were classified based on the Flow Zone Indicator (FZI) derived from core data, effectively

capturing the pore-throat characteristics controlling fluid flow. Subsequently, the XGBoost model was trained to predict HFU categories using conventional well logs (DEN, CNL, AC, RT) and derived parameters. The model achieved a high prediction accuracy (>92%), enabling the application of HFU-based permeability models across non-cored intervals and wells. The spatial distribution of HFUs revealed that sweet-spots (HFUs I & II) are predominantly developed in specific sedimentary microfacies. Critically, production data confirmed that high-rate wells are exclusively located within these predicted sweet-spot areas, validating the reliability of our method. This integrated approach provides a robust and practical tool for sweet-spot evaluation, which is crucial for optimizing well placement and development strategies in heterogeneous tight gas reservoirs.
Keywords: *highly heterogeneous, tight gas sandstone, sweet-spot evaluation, hydraulic flow unit (HFU), machine learning, Sichuan basin.*

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Analysis of the Mixing Performance of a Novel Gas Mixer

To evaluate the mixing performance of the novel mixer, a numerical simulation method was employed to investigate the internal flow field characteristics and phase volume fraction distribution. The results indicate that the maximum pressure occurs at the middle section of the central tube, and the pressure difference between this section and the outlet tube leads to the highest flow velocity within the right-hand rotating channel of the central tube. The gas emanating from the right-hand rotating channels (Layers 4 to 11) reaches the mixer's inner wall. Under the combined influence of this gas and the tangentially injected gas from the side inlet, the entire flow inside the mixer assumes a clockwise pattern. Guided by the upper and lower curved plates on the inner wall, the side-injected gas drives the surrounding flow along the inner wall toward both ends of the mixer. After impinging on the end caps, the flow reverses direction and moves along the outer wall of the central tube toward the central outlet tube, where it is discharged. Ultimately, a three-dimensional flow pattern is established: horizontally, the gas flows clockwise within each layer, while vertically, it exhibits a counter-rotating structure with counterclockwise motion in the upper half and clockwise motion in the lower half. This flow pattern effectively enhances gas mixing. This conclusion is supported by the observed uniform oxygen concentration distribution across different layers, with minimal variation. Furthermore, the relative error between the simulated and theoretical oxygen content at the outlet is only 3.65%, which further validates the high mixing efficiency of the novel mixer design.
Keywords: *static mixer, air drilling, volume fraction, numerical computation.*

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Experimental Investigation of Near-wellbore Permeability Enhancement by Hydrodynamic Cavitation Stimulation

Hydrodynamic cavitation is a promising technique for near-wellbore permeability enhancement. This study experimentally investigates the effects of organ-pipe geometrical configuration parameters, jet hydraulic power, pressure drop, discharge rate, standoff distance, and treatment duration on permeability enhancement in sandstone cores. The results show that increasing the jet hydraulic power and decreasing the hydraulic transmission efficiency, while keeping the geometrical configuration parameters within optimal value ranges, leads to high-intensity stimulation and maximizes permeability enhancement within a short treatment duration. Under a jet hydraulic power of 23.7 kW, a discharge rate of 72.9 L/min, and a pressure drop of 32 MPa, Nozzle 1 achieved maximum, average and minimum permeability enhancement rates of 102.5%, 37.2% and 22.8% respectively within the standoff distance of 0.8 m after a 30-minute treatment, demonstrating the effectiveness of hydrodynamic cavitation for near-wellbore permeability stimulation. However, the rapid permeability enhancement in rock cores near the cavitation tends to inhibit further enhancement at larger standoff distances. To achieve more uniform and sustained permeability enhancement across a broader region during long-duration treatment, it may be necessary to moderate the stimulation intensity.

Keywords: *hydrodynamic cavitation, organ-pipe nozzle, near-wellbore, permeability, stimulation.*

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Research on the Relationship between Electricity and Renewable Energy

With the continuous increase in the penetration rate of renewable energy in the power system, its volatility and intermittency pose serious challenges to the stable operation of the power grid. This article proposes a power demand and renewable energy generation prediction model based on a dual stream TBATS-CNN-LSTM hybrid neural network for the complex interaction between the power system and renewable energy. This model combines the multi seasonal processing capability of TBATS model, the spatial feature extraction capability of convolutional neural network (CNN), and the temporal dependency modeling advantage of long short-term memory network (LSTM), which can effectively capture the complex changes in renewable energy generation and power load. By constructing a comprehensive simulation system covering wind power generation, photovoltaic power generation, and traditional power loads, the superiority of the model in terms of prediction accuracy and generalization ability was verified. The research results indicate that the model can provide effective technical support for optimizing the operation of the power system under high proportion of renewable energy access, and promote the large-scale consumption of renewable energy. This work has important theoretical significance and practical value for promoting the construction of new power systems and low-carbon transformation of energy structures.

Keywords: *renewable energy, power system, TBATS, CNN, LSTM, predictive model, simulation analysis.*