

# Chemistry and Technology of Fuels and Oils

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**Комплексные методы повышения рекуперации тепла на установках  
атмосферно-вакуумной перегонки нефти**

*В работе представлен всесторонний анализ современных и перспективных технологий повышения степени рекуперации тепла на установках атмосферно-вакуумной перегонки нефти. Детально рассмотрены принципы действия, области эффективного применения, ограничения, технико-экономические показатели и проблемы внедрения следующих методов: глубокая оптимизация теплообменных сетей на основе пинч-анализа, применение конденсаторов-испарителей в ректификационных колоннах, утилизация тепла отходящих дымовых газов печей, интеграция тепловых насосов различных типов и использование тепловых аккумуляторов. Особое внимание уделено синергетическому эффекту от комбинации методов и необходимости системного подхода при проектировании и модернизации установок атмосферно-вакуумной перегонки нефти. Приведены расчетные оценки потенциала энергосбережения и экономической эффективности.*

**Ключевые слова:** установка атмосферно-вакуумной перегонки нефти, рекуперация тепла, энергоэффективность, пинч-анализ, теплообменная сеть, утилизация дымовых газов, тепловой насос, низкопотенциальное тепло.

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**A. A. Putinstev, A. V. Zuykov.**

Gubkin University

**Comprehensive Methods for Enhancing Heat Recovery  
in Crude Oil Atmospheric-Vacuum Distillation Units**

*This article presents a comprehensive analysis of modern and emerging technologies for improving the degree of heat recovery in atmospheric-vacuum distillation units. It details the operating principles, effective application areas, limitations, techno-economic indicators, and implementation challenges of the following methods: comprehensive optimization of Heat Exchanger Networks based on pinch analysis, application of condenser-evaporators in fractionation columns, utilization of waste heat from furnace flue gases, integration of various types of heat pumps, and the use of thermal energy storage systems. Particular attention is paid to the synergistic effects of combining methods and the necessity of a systems approach in designing and modernizing atmospheric-vacuum distillation units. Calculated estimates of energy-saving potential and economic efficiency are provided.*

**Key words:** atmospheric-vacuum distillation unit, heat recovery, energy efficiency, pinch analysis, heat exchanger network, flue gas heat recovery, low-grade heat.

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## **Применение концепции «умного завода» для достижения оптимальной переработки**

### **C<sub>4</sub>-фракций с установок каталитического крекинга**

*В работе представлен системный анализ роли и практического применения современных систем управления — от базового уровня (ПИД-регулирование) до интеллектуальных решений (Advance Process Control, Real-Time Optimization, цифровые двойники) — в достижении оптимальной работы установок по переработке C<sub>4</sub>-фракций. Показано, что ключевым фактором эффективности является не только выбор технологии, но и способность системы управления адаптироваться к изменчивому составу сырья, компенсировать возникающие возмущения и обеспечивать точное соблюдение оптимальных режимных параметров в реальном времени. Обосновывается необходимость перехода от локального стабилизирующего управления к интегрированным адаптивным системам, способным реализовать концепцию «умного завода».*

**Ключевые слова:** C<sub>4</sub>-фракция, каталитический крекинг, бутан-бутиленовая фракция, системы управления, Advance Process Control, Real-Time Optimization, оптимизация, цифровой двойник, нефтепереработка.

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**D. R. Kalaushin, A. V. Ostroukhov, B. P. Tumanyan.**

Gubkin University

### **Some Features of Optimal Processing C<sub>4</sub>-Fractions**

#### **from Catalytic Cracking Units in Terms of Application the “Smart Plant” Concept**

*The article provides a systematic analysis of the role and practical application of modern control systems — from the basic level (PID regulation) to smart solutions (Advance Process Control (APC), Real-Time Optimization (RTO), digital twins) – in achieving optimal operation of C<sub>4</sub>-fraction processing plants. It is shown that the key factor of efficiency is not only the choice of technology, but also the ability of the control system to adapt to the changing composition of feed, compensate for emerging disturbances and ensure accurate compliance with optimal operating parameters in real time. The necessity of transition from local stabilizing control to integrated adaptive systems capable of realizing the concept of a "smart refinery".*

**Key words:** C<sub>4</sub>-fraction, catalytic cracking, butane-butylene fraction, management systems, Advance Process Control, Real-Time Optimization, optimization, digital twins, refinery.

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### **Перспективные конструкции струйных аппаратов вакуумсоздающих систем**

*В статье рассмотрен современный уровень развития газовых и жидкостных струйных аппаратов. Показана принципиальная схема современного многосоплового парового струйного аппарата. Обоснованы, экономическая целесообразность и срок окупаемости современных паровых вакуумсоздающих систем, использующих пар низкого давления в качестве рабочей среды. Описана схема жидкостного струйного аппарата усовершенствованной конструкции, обеспечивающей меньшее гидродинамическое сопротивление и снижение энергозатрат, а также форсунки с центробежным распылом вязкой рабочей жидкости. Доказана*

*необходимость применения внутренних встраиваемых фильтрующих элементов в струйных аппаратах, показана их наиболее надежная конструкция.*

**Ключевые слова:** вакуумсоздающая система, струйный аппарат, насыщенный пар низкого давления, вязкая рабочая жидкость, центробежный распыл, защита от загрязнений.

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**I. R. Vezirov, U. R. Vezirov, E. G. Telyashev, R. R. Vezirov, R. N. Salahov.**

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### **Promising Designs of Jet Devices for Vacuum-Creating Systems**

*The article considers the current level of development of gas and liquid jet devices. A schematic diagram of a modern multi-layer steam jet apparatus is shown. The economic feasibility and payback period of modern steam vacuum-generating systems using low-pressure steam as a working medium are substantiated. The scheme of a liquid jet device of an improved design, providing lower hydrodynamic resistance and reduced energy consumption, as well as nozzles with a centrifugal spray of viscous working fluid, is described. The necessity of using internal embedded filter elements in inkjet devices is proved, and their most reliable design is shown.*

**Key words:** vacuum-generating system, jet unit, saturated low-pressure steam, viscous working fluid, centrifugal spray, protection against contamination.

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### **Механизм расчета мембранного газоразделения для проектирования и эксплуатации мембранных установок**

*В настоящее время выявлены направления использования мембранной технологии для извлечения целевых компонентов природного газа, в том числе, гелия, диоксида углерода, водорода, сероводорода и др. Совместно с профильными институтами и компаниями проводятся исследования, направленные на снижение содержания азота в добываемом газе. Разработка проектов указанных установок, а также находящихся на стадии исследований невозможна без создания математического аппарата для разработки схемных решений и расчета материально-компонентных балансов по всей технологической цепочке. В данной работе на примере создания установки мембранного выделения гелиевого концентрата показаны основные принципы разработки математической модели, используемой как на стадии проектирования, так и мониторинга работы мембранных газоразделительных установок.*

**Ключевые слова:** мембраны, газоразделение, математическая модель, очистка природного газа, установка мембранного выделения гелиевого концентрата, установка очистки газа от диоксида углерода.

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**V. A. Vagarin, V. V. Pavlenko, N. N. Kislenko.**

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## Calculation Mechanism for Membrane Gas Separation

### for the Design and Operation of Membrane Plants

Currently, areas of membrane technology use have been identified for extracting such target components of natural gas as helium, carbon dioxide, hydrogen, hydrogen sulfide, etc. Research aimed at reducing the nitrogen content in the produced gas is being conducted jointly with specialized institutes and companies. The development of projects for these units, as well as those at the research stage, is impossible without creating a mathematical apparatus for developing circuit solutions and calculating material-component balances (MCB) along the entire process chain. In this article, using the example of the creation of the UMVGK, the main principles of developing a mathematical model used both at the design stage and in monitoring the operation of membrane gas separation units are shown.

**Key words:** membranes, gas separation, mathematical model, natural gas purification, membrane helium concentrate separation unit, carbon dioxide gas purification unit.

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### Модифицированный метод оценки высокотемпературной стабильности охлаждающих низкотемпературных жидкостей

Разработан метод испытания охлаждающих низкотемпературных жидкостей с целью определения стабильности в условиях высоких (до 150°C) температур. По результатам испытаний товарных охлаждающих низкотемпературных жидкостей установлено, что неорганические ингибиторы коррозии характеризуются низкой физической стабильностью в отличие от органических ингибиторов коррозии на основе солей щелочных металлов карбоновых (дикарбоновых) кислот.

**Ключевые слова:** охлаждающая низкотемпературная жидкость, высокотемпературная стабильность, ингибиторы коррозии, дикарбоновая кислота.

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<sup>2</sup> Federal Autonomous Enterprise "The 25th State Research Institute of Chemmotology, Ministry of Defence of the Russian Federation"

### Modified Method for Assessing the High-Temperature Stability of Low-Freezing Coolants

A test method for low-freezing coolants has been developed to determine their stability at high temperatures (up to 150°C). Testing of commercial low-freezing coolants revealed that inorganic corrosion inhibitors are characterized by low physical stability, unlike organic corrosion inhibitors based on alkali metal salts of carboxylic (dicarboxylic) acids.

**Key words:** low-freezing coolant, high-temperature stability, corrosion inhibitors, dicarboxylic acid.

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## **Анализ производственных затрат технологий улавливания CO<sub>2</sub> на объектах промышленного и энергетического комплекса**

*Перспективным направлением минимизации углеродного следа представляется оптимизация эксплуатационных характеристик промышленных и энергетических объектов параллельно с внедрением передовых технологий секвестрации и утилизации диоксида углерода. В рамках данного исследования особое внимание уделено анализу современных методов и технологических решений по декарбонизации в контексте подземного хранения или подземной закачки углекислого газа для применения водогазовых методов увеличения нефтеотдачи. Рассматриваются действующие и перспективные способы улавливания углерода, сравниваются их технологические особенности, преимущества и недостатки. Дан анализ производственных затрат на улавливание и предотвращение выбросов CO<sub>2</sub> и дымовых газов в различных отраслях промышленности и на объектах энергетического комплекса: оценка экономической эффективности, стоимости, энергопотребления, затрат на технологические процессы.*

**Ключевые слова:** CCUS, технологии улавливания CO<sub>2</sub>, водогазовые методы увеличения нефтеотдачи, декарбонизация промышленных выбросов, капитальные затраты, эксплуатационные расходы, себестоимость улавливания.

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<sup>3</sup> Gubkin University,

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## **Analysis of Production Costs and Process Economics for CO<sub>2</sub> Capture Technologies at Industrial and Energy Facilities**

*A promising approach to minimizing the carbon footprint involves optimizing the operational performance of industrial and energy facilities while simultaneously deploying advanced carbon dioxide sequestration and utilization technologies. This study focuses on analyzing modern methods and technological solutions for decarbonization, particularly in the context of underground storage or injection of carbon dioxide for water-alternating-gas enhanced oil recovery. Current and prospective carbon capture techniques are examined, with a comparative assessment of their technological features, advantages, and limitations. The study includes an analysis of production costs associated with CO<sub>2</sub> and flue gas capture and emission mitigation across various industrial sectors and energy facilities: evaluating economic efficiency, cost structures, energy consumption and process-related expenditures.*

**Key words:** *carbon capture utilization and storage, CO<sub>2</sub> capture technologies, water-alternating-gas enhanced oil recovery, industrial decarbonization, power generation, capital expenditures, operational expenditures, CO<sub>2</sub> capture cost.*

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**Ингибиторы сероводородной коррозии на основе аминов и аммонийных солей, содержащих циклоацетальный фрагмент**

*Синтезированы вторичные и третичные амины, а также четвертичные аммонийные соли, содержащие циклоацетальные фрагменты. Для полученных соединений определена ингибиторная активность на углеродистой стали марки Ст3 в 3%-ном водном растворе хлорида натрия в сравнении с распространенными в нефтегазовой отрасли реагентами «Нефтехим НС» и «Нефтехим 1М».*

*Установлено, что наибольшую степень защиты проявляет третичный амин N-(1,3-диоксан-4-илметил)-N-гексилпроп-2-ен-1-амин (82%), что ненамного ниже показателей ингибиторов сравнения (94–98%), и это свидетельствует о перспективности дальнейшего поиска эффективных соединений данного класса в качестве основы новых реагентов.*

**Ключевые слова:** амины, четвертичные аммонийные соли, 1,3-диоксациклоалканы, коррозия стали, ингибиторная способность, защитный эффект, коэффициент торможения.

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**Hydrogen Sulfide Corrosion Inhibitors Based on Amines and Ammonium Salts Containing a Cycloacetal Fragment**

*Secondary and tertiary amines, as well as quaternary ammonium salts containing cycloacetal fragments, were synthesized. The inhibitory activity of the resulting compounds on St3 carbon steel in a 3% aqueous sodium chloride solution was determined, compared with the reagents «Neftekhim NS» and «Neftekhim 1M», commonly used in the oil and gas industry. It was found that the tertiary amine N-(1,3-dioxan-4-ylmethyl)-N-hexylprop-2-en-1-amine exhibited the highest degree of protection (82%), which is slightly lower than the performance of the reference inhibitors (94–98%). This indicates the potential for further research into effective compounds of this class as the basis for new reagents.*

**Key words:** *amines, quaternary ammonium salts, 1,3-dioxacycloalkanes, steel corrosion, inhibitory ability, protective effect, inhibition coefficient.*

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### **Влияние модификации целлюлозы на образование гидрата метана**

*В данной работе проводилось сравнение конверсии и скорости связывания газа при формировании гидрата метана из воды, распределенной по поверхности карбоксилированной нановолокнистой целлюлозы (CNC), модифицированной поли(2-гидроксиэтилакрилатом), альгинатом кальция, 3-(триметоксисил) пропил метакрилатом, полиметилметакрилатом или путем нейтрализации  $H^+$ -формы CNC водным раствором аммиака. Полученные данные показывают, что модификация целлюлозы хотя и снижает целевые параметры процесса, но позволяет варьировать их в широком диапазоне.*

**Ключевые слова:** гидрат метана, материалы на основе целлюлозы, метакрилаты, рост гидрата.

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### **Effect of Cellulose Modification on Methane Hydrate Formation**

*This study compares the conversion and gas binding rate during the formation of methane hydrate from water distributed on the surface of carboxylated nanofibrillar cellulose (CNC) modified with poly(2-hydroxyethyl acrylate), calcium alginate, 3-(trimethoxysilyl) propyl methacrylate, polymethyl methacrylate, or by neutralizing the CNC  $H^+$ -form with an aqueous ammonia solution. The data obtained show that although cellulose modification reduces the target parameters of the process, it allows them to be varied over a wide range.*

**Key words:** methane hydrate, cellulose-based materials, methacrylates, hydrate growth.

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### **Развитие способов оценки коррозионных процессов на объектах переработки газа**

*В статье рассмотрено исследование состава и свойств продуктов сероводородной и углекислотной коррозии с помощью методов рентгеновской дифракции и электронной микроскопии для оценки опасности процессов внутренней коррозии. Определены отличия структуры осадков сульфида железа, получаемых при сероводородной коррозии в водной и газовой фазах. Проанализировано воздействие состава эксплуатационных сред на образование и защитные свойства сидеритов стехиометрического и нестехиометрического составов, являющихся продуктом углекислотной коррозии. Для получения осадков использованы новые способы коррозионных испытаний, имитирующие условия эксплуатации на объектах переработки газа. Приведены примеры использования характеристик кристаллической структуры сидеритов по результатам обработки и анализа результатов замеров методом рентгеновской дифракции для определения степени опасности локальной коррозии на стали.*

**Ключевые слова:** сероводородная коррозия, углекислотная коррозия, продукты коррозии, анализ состава отложений, метод рентгеновской дифракции.

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### **Development of Methods for Assessing Corrosion Processes at Gas Processing Facilities**

*The article considers the study of the composition and properties of hydrogen sulfide and carbon dioxide corrosion products using X-ray diffraction and electron microscopy to assess the danger of internal corrosion processes. The differences in the structure of iron sulfide deposits obtained during hydrogen sulfide corrosion in the aqueous and gas phases are determined. The effect of the composition of operating environments on the formation and protective properties of stoichiometric and non-stoichiometric siderites, which are products of carbon dioxide corrosion, is analyzed. New corrosion testing methods simulating operating conditions at gas processing facilities are used to obtain deposits. Examples of using the characteristics of the crystalline structure of siderites based on the results of processing and analysis of X-ray diffraction measurements to determine the degree of danger of localized corrosion on steel are given.*

**Key words:** hydrogen sulfide corrosion, carbon dioxide corrosion, corrosion products, deposit composition analysis, X-ray diffraction method.

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### **Нерешенные проблемы по геологии и разработке нефтяных месторождений**

*Для описания процесса восполнения запасов нефти и прогноза на будущее создана и апробирована математическая модель. Расчеты показали, что по мере исчерпания извлекаемых запасов скорость образования нефти сравнивается с уровнем добычи нефти, и данная тенденция может продолжаться сотни лет. Предложен метод расчета коэффициента извлечения нефти с учетом естественного процесса восполнения запасов. Показано, что большая часть дополнительно добытой нефти обуславливается природными факторами, а не воздействием человека на пласт.*

**Ключевые слова:** происхождение нефти, восполнение запасов, нефтеподводящие каналы.

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NCP «Russian Scientifically - Technical Society»

### **Unsolved Problems in Geology and Development of Oil Fields**

*A mathematical model was created and tested to describe the process of replenishment of reserves and the scenario for the future. Calculations have shown that as recoverable reserves are depleted, the rate the origin of oil is compared with the level of oil production, and this trend can continue for hundreds of years. A method for calculating*

*oil recovery factor taking into account the natural process of reserve replenishment is proposed. It has been shown that most of the additional oil is caused by natural factors, and not by EOR and IOR impact.*

**Key words:** *origin of hydrocarbons, replenishment of reserves, oil delivery channel.*

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### **Some Aspects of the Influence of Additives on the Precipitation of Wax in Oil**

*This study investigates the physicochemical properties of crude oil from the Novosamarskoye field in the presence of a polymer additive and molybdenum disulfide (MoS<sub>2</sub>). The selected crude oil sample is prone to wax deposition. Rheological measurements, differential scanning calorimetry, and complementary techniques were employed to characterize the key parameters of the systems under study. Two independent methods provided consistent values for the wax appearance temperature (WAT) of the crude oil, which was found to be slightly above 25°C. The effects of the polymer (EVA 11) and MoS<sub>2</sub> additives on viscosity were examined at shear rates of 1 and 100 s<sup>-1</sup>. The role of these additives in the quantity of deposits formed and the temperature of their formation is discussed.*

**Keywords:** *crude oil, rheology, wax, WAT, EVA, deposition rate.*

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### **Research on Production Data Mining and Steam Injection Timing Intelligent Decision System for Heavy Oil Thermal Recovery Well Groups**

*In the process of heavy oil steam injection development, the production performance of well groups often exhibits nonlinearity and high uncertainty. Traditional decision-making methods for steam injection timing, which rely on manual experience and static analysis, fail to meet the dynamic needs of reservoir development. To address this issue, this study establishes a production data mining model and, based on full utilization of production data, builds an intelligent decision-making model for steam injection timing. Through case analysis, the study demonstrates the advancement of the intelligent decision-making model and lays a foundation for further promoting the development of heavy oil steam injection. Research results show that by applying the system to five typical well groups in a certain oilfield, the average production increase reached 17.6%, steam injection savings were between 15% and 25%, and the decision accuracy exceeded 90%. This significantly improved recovery efficiency and economic benefits. The conclusion indicates that the intelligent decision system can provide scientific, precise, and efficient technical support for heavy oil thermal recovery and has broad prospects for application and promotion.*

**Keywords:** *heavy oil thermal recovery; production data; data mining; steam injection timing; intelligent decision.*

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### **Static Correction Processing Technology and Its Application to Improve the Imaging Accuracy of Low-Amplitude Structures**

*A deep clastic rock reservoir, located at a depth exceeding 4500 meters, has an effective thickness of approximately 5-8 meters and a structural amplitude less than 10 meters. After conventional processing, the horizontal distribution of event lines in the final imaging does not accurately reflect the true distribution of sand bodies, especially in low-amplitude structural zones. Inaccurate imaging of sand bodies due to inaccurate imaging of low-amplitude structures often leads to drilling failures. To address the challenge of accurate imaging of deep low-amplitude structures, the first step is to solve the static correction problem, followed by consideration of imaging velocity issues. The inaccurate imaging of deep thin sand bodies caused by static correction is an urgent problem to be solved. Therefore, this project proposes a method that combines 3D-tomographic static correction with 3D-refraction residual static correction and target layer time window inversion for maximum energy surface consistency residual static correction. This method effectively solves the static correction problem for imaging deep low-amplitude thin sand bodies in the western region. The theoretical basis, processing procedures, combination schemes of key parameters, and their interactions for these three methods are elaborated in detail. The application effect of this static correction technical scheme in the exploration of low-amplitude structures in the western region is demonstrated. Drilling verification shows that the proposed method is feasible. According to the obtained conclusions, the error between the calculated well depth and the actual drilling point is small, greatly improving the success rate of drilling.*

**Keywords:** tomographic static correction, refraction residual static correction, layer-wise residual static correction.

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### **Heavy Oil Production Forecasting Using Steam-Assisted Gravity Drainage**

*In view of the production forecasting problem in Steam Assisted Gravity Drainage (SAGD) heavy oil development, this study proposes a novel SAGD production forecasting model. The research first introduces the model from the perspectives of overall framework, data sources and preprocessing, and model method selection. On this basis, a case study is carried out with data from a domestic oilfield to demonstrate the application of the SAGD production forecasting model, providing a foundation for improving the prediction accuracy. The results show that the constructed model can effectively capture the dynamic variation characteristics of production, with the average relative error controlled within 5%. Its fitting accuracy is significantly superior to traditional empirical models and numerical simulation methods. The conclusion indicates that the SAGD production forecasting model not only provides a reliable tool for production prediction in SAGD development, but also offers theoretical support and*

*practical value for optimizing injection–production parameters and improving the efficiency of heavy oil resource development.*

**Keywords:** *SAGD heavy oil development, production forecasting, prediction model, model construction, model application.*

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### **Experimental Investigation on Shale Thermal Properties and Thermo-Poroelastic**

#### **Analysis of Wellbore Stability in Shale Formation**

*During deep shale oil and gas exploitation and development, wellbore instability is a big challenge and thermo-poroelastic wellbore stability analysis is a powerful tool to obtain the safe drilling mud density window. XRD results show that shale in the three layers of Puguang gas reservoir contained maximumly 35.5% of clay minerals and the main type of minerals are chlorite, illite and interlayered illite with montmorillonite. In the thin-section electron microscopy pictures, beddings can be observed in sample from A layer. Thermal conductivity was tested with laser flash method, and it ranges from 2.01 to 3.50 W/m·K for shale in the three layers at formation temperature. Linear thermal expansion coefficient changes from  $5.62 \cdot 10^{-6}$  to  $8.09 \cdot 10^{-6} \text{ K}^{-1}$ . At higher temperatures, thermal conductivity will reduce while the thermal conductivity increases gradually first and at temperature exceeding  $500^\circ\text{C}$ , rapid increase occurs. Among three layers, wellbore in layer B has the highest collapse pressure and the narrowest window, which is 1.57-1.83 g/cm<sup>3</sup>. When the wellbore cools down by  $20^\circ\text{C}$ , it changes to be 1.56-1.80 g/cm<sup>3</sup>. Cooling can help reduce the collapse pressure and is beneficial for wellbore stability.*

**Keywords:** *shale, thermal conductivity, thermal expansion, thermo-poroelastic, wellbore stability.*

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### **Research on Optimization Methods for Management of Electric Thermal Gas Multi Energy Systems**

*In response to the problem of insufficient multi-source heterogeneous data fusion and uncertainty quantification mechanism in load forecasting of integrated energy systems, a convolutional neural network (CNN) is used to extract local features of load data, and a bidirectional long short-term memory network (BiLSTM) is used to capture bidirectional temporal dependencies. Random forest (RF) is used to process high-dimensional nonlinear relationships, and kernel density estimation (KDE) is used to quantify prediction uncertainty, thus establishing a CNN BiLSTM RF-KDE hybrid model; At the same time, a multi energy flow coupling model of electricity heat gas is constructed to analyze the impact of different carbon price ranges on scheduling strategies. The example analysis shows that the determination coefficients for predicting power and heat loads on the training set are 0.93 and 0.97, respectively; The determination coefficients for predicting power and heat loads on the test set are 0.79 and 0.85,*

respectively. The predicted power generation and heat generation of each device are highly consistent with the average trend, indicating that the use of this model can obtain a load that is closer to the accurate value. Based on this data, more reliable analysis and scheduling of the integrated energy system can be carried out.

**Keywords:** multi energy system, load forecasting, convolutional neural network, bidirectional long short-term memory network.

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### **Analysis of Rock Physics Variation Patterns and Time-Lapse Seismic Response Characteristics**

*Targeting remaining oil-gas prediction challenges in late-stage Chinese oilfield development, this study takes the DF gas field as a case and integrates core, logging, and seismic data to conduct time-lapse seismic petrophysical analysis and forward modeling. Core tests show P- and S-wave velocities decrease with rising gas saturation and pore pressure, with P-wave velocity exhibiting a distinct inflection point at ~40% gas saturation. Model comparisons verify that the calibrated White gas-patch model characterizes gas-bearing reservoir acoustic responses more accurately than the Gassmann model. Single- and multi-factor time-lapse seismic forward modeling reveals that reservoir pressure decline, gas saturation reduction, and gas-water interface rise jointly weaken seismic amplitude energy, resulting in negative time-lapse differences. Further validation via typical single-well forward modeling confirms pressure decline as the dominant control factor for the DF gas field's time-lapse seismic responses. The established petrophysical interpretation charts and time-lapse difference response patterns provide a reliable theoretical and methodological basis for quantitatively evaluating remaining gas distribution using actual time-lapse seismic data.*

**Keywords:** time-lapse seismic, rock physics; forward modeling, remaining gas prediction, patchy saturation model.

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### **Model Applicability of Characterizing Shale Pore Structure by Low-Pressure Nitrogen Adsorption Method**

*In order to select calculation methods to accurately characterize the pore size distribution of shale microporous and mesoporous, 3 synthesized standard samples were chosen for this study to perform contrastive analysis of results of the BJH adsorption method, the BJH desorption method and NLDFT method. The research shows that the NLDFT method is preferred to characterize pore size distribution of shale samples with both mesoporous and microporous. When the BJH adsorption method or BJH desorption method is used to calculate the shale pore size distribution, the microporous will be ignored, which allows the methane adsorption capacity of the shale sample to be significantly underestimated.*

**Keywords:** *low-pressure nitrogen adsorption, shale, pore structure, BJH, NLDFT.*

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### **Research on Oil Pipeline Balance Control Method Based on Hierarchical Architecture and Scheduling Optimization Model**

*To solve the complex control problem of balancing economic efficiency, safety and stability in the scheduling optimization process of long-distance oil pipelines, this paper had constructed and verified an oil transportation equilibrium control method based on a hierarchical architecture and scheduling optimization model, including upper-level scheduling optimization layer for global economic planning over long periods using a computationally efficient steady-state hydrodynamics model, and the middle-level coordination control layer for dynamic tracking and disturbance suppression in short periods, embedding a high-precision discretized transient hydrodynamics model into the model predictive control algorithm. The results showed that under normal operating conditions, compared with traditional manual scheduling, the hierarchical optimization strategy can save approximately 61.3% of energy consumption, and reduce the standard deviation of pressure fluctuations at the end of the pipeline from 0.511 MPa to 0.200 MPa, achieving perfect pressure stability. When facing sudden disturbances such as increased demand or equipment failures, this method can quickly restore stability within 1-2 minutes, avoiding dangerous pressure overshoots and operational interruptions. Moreover, this framework had multi-objective optimization capabilities, allowing decision-makers to weigh different strategies such as “energy conservation priority” and “stability priority” based on operational needs. For example, achieving the ultimate stability required a 36% higher energy cost compared to the energy-saving mode.*

**Keywords:** *oil pipeline, balance control method, hierarchical architecture, scheduling optimization model.*

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## **Research on the Influence of Fractures on Rock Mechanical Properties of Limestone and Stress around Wellbore**

*Limestone reservoir resources of the Taiyuan formation in the Ordos Basin have huge potential and its efficient development is of great significance for Chinese energy industry. But the well-developed and random distribution of natural fractures put a huge impact on rock mechanics and wellbore stress, leading to frequent drilling fluid leakage and significant differences of reservoir stimulation, which restricts the production. Therefore, this study uses SEM, CT imaging, mechanical tests and numerical simulation to analyze how fracture development affects rock mechanics and wellbore stress. Rock is mainly composed of calcite/dolomite and has high brittleness. Natural fractures with different scales are noticed, weakening rock integrity. Mechanical experiments show that rock strength increases with growing confining stress due to this radial constraint on fracture displacement. Also, because of the difference of fracture number and distribution, rock mechanical parameters are varying. Numerical simulation reveals that borehole fractures induce an asymmetric shift in wellbore stress distribution, with stress concentration prone to occur at fracture tips. This triggers fracture propagation and exacerbates leakage risk. Under fracture condition, the distribution of stress and rock strength are more complex. The fracture initiation points around the wellbore and the dominant position of fracture propagation are not completely controlled by in-situ stress, which easily leads to significant differences in the volume of hydraulic fracture network. Results in this paper are able to guide drilling design and fracturing optimization for fractured reservoirs.*

**Keywords:** limestone reservoir, natural fracture, drilling fluid leakage, hydraulic fracture.

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## **Simulation Study on Fracture Propagation and Formation Deformation of Shale Fracturing Based on Cohesive Unit**

*In order to deeply study the crack propagation law in the fracturing process of shale reservoirs and its influence on the stress and displacement fields near the wellbore, a numerical model of globally embedded zero-thickness Cohesive element is constructed in this paper, and the in-situ stress field and seepage field are coupled. By self-evolving complex fracture paths, the model can more truly reflect the mechanism of horizontal in-situ stress difference, formation elastic modulus and injection flow on complex fracture propagation. The results show that the complex fracture network formed by volume fracturing makes the reservoir stress and displacement field highly non-uniformly distributed, especially in the near-wellbore area. The ‘ stress deficit ‘ and the uneven propagation of fractures lead to inconsistent weakening of the axial and radial constraints of the far wellbore to the near wellbore, resulting in non-uniform stress and displacement responses. The influence degree of horizontal ground stress difference, formation elastic modulus and injection flow on Mises stress and formation displacement is as follows: injection flow is dominant, formation elastic modulus is second, and horizontal ground stress difference is the weakest. The specific performance is that the formation displacement increases with the increase of horizontal*

stress difference, decreases with the decrease of formation elastic modulus, and increases significantly with the increase of injection flow rate.

**Keywords:** crack propagation, cohesive unit, ground displacement, fluid-solid coupling, hydraulic fracturing.

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### **Experimental Study on Solvent Extraction for Heavy Oil Recovery Mechanism**

*In this study, a series of solvent extraction experiments were conducted to evaluate the effects of different single solvents and p-xylene-assisted composite solvents on heavy oil recovery, sand surface wettability, and the interfacial interaction mechanism. Results showed that p-xylene exhibited a distinct synergistic effect with aromatic solvents, particularly toluene, improving heavy oil recovery by up to 3.3%, whereas its combination with n-pentane caused a significant reduction in recovery due to the precipitation of heavy components such as asphaltenes. Contact angle measurements further confirmed that hybrid solvent systems enhanced the hydrophilicity of sand surfaces, with the [p-xylene]-n-pentane system showing the greatest decrease (14°) in contact angle. Zeta potential analysis revealed that sand particles possess a positive charge, while bitumen droplets carry a negative charge, confirming the electrostatic interaction that contributes to their adhesion. This work provides new insights into the synergistic mechanism of mixed solvents in bitumen extraction and highlights the potential of aromatic-assisted solvent systems for improving the efficiency of heavy oil separation. MD simulations further revealed that toluene most effectively promoted the dispersion and diffusion of heavy-oil SARA fractions. Mean square displacement analysis showed that saturated and asphaltene molecules exhibited the highest mobility in toluene, while colloids remained the least diffusive. Radial distribution function results confirmed strong □-□ interactions between toluene and aromatic/asphaltene components, facilitating their structural disaggregation. Concentration and conformational analyses demonstrated that all four heavy-oil components gradually transitioned from aggregated states to dispersed equilibrium under toluene solvation. These molecular-scale insights corroborate experimental observations and elucidate the mechanism by which aromatic-assisted solvent systems improve the efficiency of heavy-oil separation.*

**Keywords:** heavy oil, solvent extraction, oil sands, contact angle, molecular dynamics simulation.

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### **A new Method for Calculating Dynamic Reserves of Fractured-Vuggy Reservoirs Considering Dissolved Gas Precipitation**

*The conventional material balance method considers the impact of crude oil, rocks, and their bound water on the calculation of dynamic reserves, but does not consider the distribution characteristics of oil and water in fracture-vuggy reservoirs to consider the coexistence of internal oil and water bodies, or water bodies connected to the outside, as well as the impact of dissolved gas precipitation as the reservoir develops. Based on the distribution characteristics of oil and water in fracture-vuggy reservoirs, a dynamic reserve correction calculation model considering the influence of degassing is established. This correction calculation model is used to calculate the three example wells A, B, and C that produce a large amount of gas in the fracture-vuggy reservoirs. Compared with the conventional dynamic reserve calculation model, the results show that there is a significant difference before and after the calculation of the three wells, with an error of over 20%. The maximum error of well C is 45.42%. It indicates that a large amount of gas is dissolved in the three well reservoirs, and a large amount of dissolved gas is released during the reservoir development process, resulting in a decrease in the reservoir volume. The calculation results are more in line with the actual reservoir.*

**Keywords:** material balance method, fracture-vuggy reservoirs, dynamic reserve calculation model, dissolved gas.

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### **An Application of Data Reconciliation in Flow State Monitoring for Compressor Stations**

*For the construction of natural gas transmission pipeline digital twin, real-time simulation is crucial for obtaining gas flow state from measurements. However, random noise and gross errors in the station measurements significantly influence simulation results, while the measurement redundancy along the pipeline is limited for gross error detection. To address this issue, this study systematically analyzes the intrinsic mechanism of correntropy-based robust data reconciliation in compressor stations, with the trace of the information matrix employed as a key numerical diagnostic indicator. First, a reconciliation framework is established to estimate flow states from redundant pressure and flow measurements that may contain gross errors, with the physical laws of the station incorporated as equality constraints in the optimization model. Then, by introducing quantitative diagnostics such as the trace of the information matrix and process variance, this work analyses the internal conflict-evolution mechanism of reconciliation process in the station. The effectiveness of reconciliation is validated in a real-world station. The results demonstrate that the gross error in outlet station pressure measurements is effectively suppressed. Theoretically, the trace of information matrix is reduced by shortening the window width of correntropy function, thereby enhancing the consistency between reconciled data and the physical model. This study provides valuable insights for sensor fault detection and suppression in compressor station operation and monitoring.*

**Keywords:** gross errors suppression, information matrix, data reconciliation, compressor stations.

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## **A Study on Productivity Prediction Methods for Low-Porosity and Low-Permeability Sandstone Reservoirs After Fracturing Stimulation**

*Addressing the current practice of multi-layer commingled testing in the Subei Basin, the productivity results of commingled tests were allocated to individual layers by comprehensively considering parameters such as porosity, permeability, formation thickness, and deep induction resistivity. This established a relatively scientific productivity allocation method, effectively resolving the issue of productivity partitioning. Through the analysis of productivity-influencing factors, it was found that in Type I and Type II reservoirs, when the production intensity is below a certain threshold value, well-logging data can still reflect most of the formation information. In this case, acoustic time difference, porosity, permeability, and actual fracturing pressure can effectively indicate the post-stimulation production intensity. However, when the production intensity exceeds the threshold, well-logging data can only reflect a small portion of the formation information. Here, the fracability of the reservoir and engineering factors play a decisive role. Consequently, only the brittleness index and actual fracturing pressure can effectively reflect the post-stimulation production intensity. A quantitative productivity evaluation model was established based on the identified productivity-influencing factors. Analysis indicates that this method is suitable for early-stage productivity prediction, as it is highly correlated with well-logging parameters that characterize the reservoir's original state. In the studied area, the post-stimulation productivity of the reservoir can not only be qualitatively evaluated but also quantitatively assessed with high precision, achieving an absolute error within  $\pm 0.5$  t/d. This systematic summary, combined with statistical analysis and production practices, further refines the productivity prediction method for low-porosity and low-permeability sandstone reservoirs after fracturing stimulation.*

**Keywords:** *Subei Basin, low-porosity and low-permeability sandstone, reservoir fracturing stimulation, productivity prediction.*

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## **Numerical Study on Enhanced Heat Transfer Using Cross-Type Plate Heaters in Underground Wells for In-Situ Oil Shale Mining**

*Efficient heat transfer is crucial for improving the thermal performance and service life of downhole heaters used in in-situ oil shale extraction. In this study, a variable-pitch spiral baffle perforated-plate heater was designed, and the effects of different decreasing baffle pitches on heat transfer and flow characteristics were numerically investigated using the RNG  $k-\epsilon$  turbulence model. The computational domain was meshed in ANSYS Workbench, with grid-independence verified through multi-scale mesh comparison. Results show that the wall temperature of the heating plate generally increases along the flow direction, while the heat transfer coefficient decreases, reaching its maximum at the inlet. Smaller baffle pitches prolong gas residence time, intensify turbulence, and enhance convective heat transfer, leading to lower wall temperatures and improved thermal uniformity. The perforated wall surface exhibits consistently lower average temperatures than the non-perforated surface, indicating more effective heat exchange. Moreover, reducing the baffle pitch significantly decreases both the mean wall temperature and the temperature difference, mitigating thermal stress and extending heater lifespan. A comprehensive performance evaluation based on the dimensionless index  $h\sqrt{P}^{1/3}$  reveals that heater performance first increases and then decreases with pitch size, achieving optimal performance at a 200 mm pitch, approximately 84.6% higher than that at 100 mm. This study provides theoretical guidance for optimizing heater geometry to achieve a better balance between heat transfer enhancement and flow resistance, supporting the development of high-efficiency in-situ oil shale extraction technologies.*

**Keywords:** variable-pitch helical baffle, perforated heating plate, convective heat transfer, thermal-hydraulic performance, CFD simulation, oil shale in-situ conversion.

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## **Evaluation of Oil/Water Emulsion Properties Stabilized by SiO<sub>2</sub> Nanoparticles and Study on Oil Displacement**

*With the gradual depletion of conventional recoverable oil reservoirs, enhancing crude oil recovery has emerged as a critical challenge in oilfield development. This study conducts systematic experimental investigations into the performance and enhanced oil recovery mechanisms of oil-in-water emulsions stabilized by SiO<sub>2</sub> nanoparticles, aiming to provide technical support for the efficient exploitation of complex reservoirs. By preparing oil-in-water emulsions stabilized with SiO<sub>2</sub> nanoparticles, key properties including viscosity, wetting contact angle, droplet size, and interfacial tension with crude oil were measured. Core flooding experiments were performed using three cores with varying permeability levels, involving water flooding, emulsion flooding, and secondary water flooding, with analyses of pressure variations, cumulative liquid production, and oil production data. Results demonstrate that the formulated emulsion exhibits superior performance, surface tension of 28.383 mN/m, and interfacial tension with crude oil of 2.853 mN/m, the contact angle with the rock is 17.109°, and the average droplet size is approximately 30.61 μm, and it has good colloidal stability and uniform dispersion. The emulsion flooding significantly enhanced*

oil recovery, increasing the recovery rate by 37.50% for the medium-permeability Core 2, with a final total recovery rate reaching 81.25%, while also modifying flow paths and enhancing conformance control. The injection pressure during emulsion flooding showed a typical pattern of rapid increase, fluctuation due to pore blocking, followed by stabilization, indicating dynamic plugging and breakthrough behavior. This study provides experimental evidence for the application of SiO<sub>2</sub> nanoparticle-stabilized emulsions in enhanced oil recovery and offers feasible experimental foundations and process recommendations for the demonstration of nanoparticle emulsions in unconventional and complex reservoirs.

**Keywords:** silica nanoparticles, contact angle, performance evaluation, emulsion.

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### **Experimental Study on the Mechanism of Carbon Dioxide Injection for Coal Rock Gas Production Increase**

China's deep coal rock gas resources are abundant, but its efficient development faces challenges such as low permeability of reservoirs, huge water consumption and environmental pressure. To address the above problems, this paper discusses the technical path of replacing traditional hydraulic fracturing with CO<sub>2</sub> as fracturing medium. Through indoor physical simulation experiments, the three core mechanisms of CO<sub>2</sub> fracturing are systematically investigated: supercritical CO<sub>2</sub> and CO<sub>2</sub> foam fracturing can form a complex network of seams, which is significantly more complex than that of conventional hydraulic fracturing; CO<sub>2</sub> has a significant competitive adsorption and displacement effect on CH<sub>4</sub>, which can effectively improve the methane recovery rate; and the solvation effect of CO<sub>2</sub> on the matrix of the coal can enlarge pores and improve seepage channels. On this basis, a set of high-performance CO<sub>2</sub> foam fracturing fluid system was developed, which has stable temperature and shear resistance, and good foaming, stabilizing and sand-carrying capacity. 25 wells field tests show that compared with conventional hydraulic fracturing, CO<sub>2</sub> pre-fracturing and CO<sub>2</sub> foam fracturing can achieve about 15% and 18% yield enhancement, respectively, and save more than 50% water, and at the same time, achieve partial CO<sub>2</sub> fracturing. geological storage of CO<sub>2</sub>. This study provides an important theoretical basis and technical support for water reduction, efficiency development and carbon emission reduction of deep-seated coal rock gas.

**Keywords:** coal rock gas; CO<sub>2</sub> fracturing; complex seam network; production increase; water saving.

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### **Preparation and Performance Optimization of Chemical Anti-Corrosion Coatings for Mechanical Oil Recovery Equipment in Oilfield Development**

*This paper focuses on the preparation and performance optimization of chemical anti-corrosion coatings for mechanical oil recovery equipment. It systematically studies the selection of coating raw materials, the design of coating formulations and the optimization of preparation processes. Five types of anti-corrosion coatings, namely epoxy resin coatings, polyurethane coatings, fluorocarbon coatings, polyamideimide coatings, and composite coatings, are prepared and tested. The performance of these coatings is evaluated from multiple aspects including corrosion resistance, adhesion strength, wear resistance, and high-temperature stability. Through single-factor experiments and orthogonal experiments, the optimal formulation and preparation process parameters for each coating are determined. Field application tests show that the optimized composite anti-corrosion coating has the best comprehensive performance, with a corrosion inhibition rate of over 98% and a service life extended by more than 3 times compared to traditional coatings. This study provides a theoretical basis and practical guidance for the application of anti-corrosion coatings in mechanical oil recovery equipment, and contributes to the safe and efficient development of oilfields.*

**Keywords:** oilfield development, mechanical oil recovery equipment, anti-corrosion coating, coating preparation, performance optimization.

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### **Modeling Transient Pressure Behaviors of Multi-Fractured Horizontal Wells in Multilayered Tight Gas Reservoirs with Crossflow And Stress Sensitivity**

*Tight sandstone gas reservoirs are characterized by heterogeneity and multi-layers, and multi-stage fracturing horizontal wells (MFHWs) are commonly adopted to achieve efficient exploitation. The inter-layer cross flow and stress sensitivity during production make it challenging to accurately characterization of the pressure behaviors of MFHWs. This work presents for the first time an analytical model to investigate the transient pressure behaviors of MFHWs in stratified tight gas reservoirs, incorporating the vertical heterogeneities of layer properties, cross-flow between adjacent layers, and the stress sensitivity. The point-source function, Laplace transformation coupled with Pedrosa's transformation and perturbation technique are adopted to obtain the analytical solution of transient pressure responses. The proposed model is validated against a commercial software designed for transient pressure analysis, and the transient pressure behaviors of MFHWs in multi-layered tight gas reservoirs are analyzed.*

*Sensitivity analysis reveals that larger cross-flow coefficient causes an earlier start of the crossflow regime in the transient pressure behaviors. The influence of stress sensitivity is more pronounced during intermediate-time and late-time productions. The model and corresponding conclusions can be used to interpret pressure data more accurately for multilayered tight gas reservoirs with crossflow and stress sensitivity and provide more accurate dynamic parameters which are important for gas reservoir exploitation.*

**Keywords:** *stress sensitivity, layered gas reservoir, inter-layer crossflow, multi-fractured horizontal well, pressure transient analysis.*

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### **Structural Optimization and Unsteady Hydraulic Characteristics of a Rotor–Stator Valve in a Continuous-Wave Pulsar**

*The continuous-wave pulsar is a key tool for high-rate mud-signal transmission, and the structural parameters of its rotor–stator throttling unit directly affect the pressure-wave amplitude and hydraulic-torque characteristics. A three-dimensional CFD model incorporating the valve-port throttling zone and the radial-gap flow channel was established using the SST  $k-w$  turbulence model, forming a research route of “steady-state structural optimization–transient characteristic verification”. The steady-state simulations show that the rotation termination angle exerts a significant nonlinear influence on the throttling pressure drop, with the effective strong-throttling interval located at 26–30°. Blade thickness has little effect on the pressure drop but strongly affects the hydraulic-torque response. Considering the pressure-drop plateau and torque response, the optimal structural parameters are a blade thickness of 6.5 mm and a rotation termination angle of 28°. Transient simulations indicate that the sensitivity of pressure-wave amplitude to the investigated factors, from strong to weak, is as follows: flow rate and rotor–stator gap; density and operating frequency; and viscosity. These results provide a theoretical basis for structural design and for matching field operating parameters of continuous-wave pulsars.*

**Keywords:** *continuous-wave pulsar, rotor–stator valve, structural optimization, flow-field analysis, pressure-wave amplitude, hydraulic torque.*

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### **Preparation and Performance Evaluation of Acidic Clay Stabilizer**

*Clay stabilizers are essential for inhibiting clay mineral swelling and migration. Given the shortage that polycationic clay stabilizers may block pores in tight reservoirs, a degradable polycationic clay stabilizer (ACS) was developed in this work. It can gradually hydrolyze at formation temperature, and produce hydrogen ions, showing the characteristics of acid. The ACS was synthesized by N, N, N', N'- Tetramethyl ethylenediamine and Chloroacetic anhydride. Experiments of anti-swelling, swelling-restoration, hydrolysis, and dissolution at temperatures from 30 to 100 °C were carried out. A maximum anti-swelling rate of 87.04% was achieved at 3% concentration. The swelling-restoration rate at ambient temperature was 20.69% under the experimental conditions. The ACS slowly hydrolyzes into a low-molecular-weight stabilizer and release hydrogen ions as temperature increases. Moreover, hydrolysis is intensified with the increase in temperature. At 95°C, the dissolution rate of limestone can reach 27.23% when the concentration of ACS is 3%. These performances make ACS play the role of polycationic clay stabilizer in hydraulic fracturing construction, and automatically degrade after hydraulic fracturing. And it has a certain dissolution performance. This not only avoided the problem that the adsorption of polycationic clay stabilizer occupies pore space, but also can improve pore space to some extent.*

**Keywords:** fracturing, clay stabilizer, clay swelling, degradation.

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### **Structural Parameter Optimization Simulation of Progressing Cavity Pump for Sandy Heavy Oil**

*When extracting sandy heavy oil, progressing cavity pumps (PCPs) often face mismatches between well conditions and pump selection. To balance power, efficiency and wear, this study built a 3D CFD-based flow-structural coupling model (with dynamic mesh) for GLB120 PCPs conveying oil-water-sand mixtures. It analyzed how clearance, lead and eccentricity affect flow, performance and stator deformation under sandy/pure-liquid conditions. Results show uniform pressure/velocity in the pump chamber, but sharp changes near the stator-rotor meshing line. For pure liquid, small clearance, large eccentricity/lead improve performance; for sandy oil, extreme clearance raises loss/wear, while excessive lead/eccentricity increases leakage. Optimal parameters for sandy heavy oil: clearance – 0.9–1□particle diameter, eccentricity – 5 mm, low lead (150 mm, multi-stage). This guides structural optimization for metal/rubber PCPs..*

**Keywords:** PCP, structural optimization, simulation, sandy heavy oil.