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RESEARCH PAPER

Application of nanotechnology in petroleum exploration and development

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Abstract: Combined with the actual demand of oil and gas exploration and development, this paper summarizes the research progress and application of nanotechnology in various fields of petroleum exploration and development, discusses and prospects the application and development of nanotechnology in the future. Nano characterization technology has played an important role in the analysis of the mineral composition, micro pore structure and rock physical properties of unconventional reservoirs; the reservoir nano sensor is still in the laboratory stage, and the reservoir nano robots still need a key technology breakthrough; numerical simulation technology of oil and gas migration in micro-nano porous media will become an important means of unconventional oil and gas migration mechanism, distribution pattern and resource evaluation; nano materials have size and surface effect, wetting characteristics, inhibition characteristics of particle migration, shear thickening behavior, nanometer photocatalytic properties, nano filtration and nano corrosion and wear resistance. Nano materials have broad application prospects in the fields of enhanced oil recovery, water treatment, engineering anti-corrosion. There are three aspects of future development of nanotechnology, i.e., nano characterization and numerical simulation, nano sensing and nano materials. In-situ modification of low grade oil and gas resources and synthesis of oil and gas by nano photosynthesis are the two potential development directions.

Key words: nanotechnology; nano characterization; nano sensing; numerical simulation in micro-nano porous media; nano materials; research progress; development directions

Introduction

Nanotechnology, information technology and biotechnology are three major motivations for technological innovation and development in the 21st century. Bai Chunli, academician of Chinese Academy of Sciences, defined "nanotechnology" as the scientific technology to manufacture materials by using single atom or molecule, which treats the property and application of materials with structural size of 1–100 nm[1]. Nanotechnology includes the design and manufacture of nano-materials and the nano-measurement, and it has been widely applied in the sectors of electronics, biology, medical treatment, aviation, military and energy resource. Nano-materials have been the research focus on academic and industrial circles because of their unique optical, electrical, thermal and magnetic properties that are derived from the scale effect, and they have gradually stepped into the research fields of traditional fossil energy and new energy. It is predicted that the primary energy will remain predominant in the mid-21st century[2]; with the continuous deepening of oil and gas development, however, the quality of conventional oil and gas resources becomes lower and their development is faced with more and more difficulties. On the other hand, the development efficiency of unconventional oil and gas resources is lower because the existing technologies do not meet the development requirements. In the current background that exploration and development of oil and gas resources becomes more and more difficult, the continuous innovation and further application of nanotechnology promote the rapid development of traditional petroleum development technologies, and have achieved the following intermediate research results[3–5]. Firstly, nano fine characterization technology facilitates the effective reservoir space evaluation[6–9]. Secondly, nano-sensing and developing technology increases the monitoring level and description precision of oil reservoir characteristic parameters[10–13]. Thirdly, nano-molecule simulation technology reveals accurately the oil and gas adsorption and desorption mechanism and the oil and gas migration laws in non-Darcy model[5–6]. And fourthly, new nano-materials provide technically the effective support for well drilling, tight oil and gas

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reservoir stimulation, enhanced recovery and so on.

In this paper, the current researches of nanotechnology in the petroleum exploration and development are extensively reviewed. Based on the actual demand of oil and gas exploration and development, the research progresses and application situations of nanotechnology in the petroleum exploration and development are illustrated from four aspects, i.e., nano-characterization, nano-sensing, numerical simulation of fluid migration in micro-nano porous media and nano-material. Finally, the application and development of nanotechnology in the future are discussed and prospected.

1. Nano-characterization technology

Nano-material is the foundation of nanotechnology, and its unique characteristics are derived from nano-scale effect. Therefore, the accurate characterization of nano-material is essential to nanometer research. The innovation of nano-characterization technology promotes continuously the development of new nanotechnology. Reservoirs are the porous material composed of various mineral particles in a certain structure with quite strong heterogeneity, and there are a large number of micro-nano mineral particles, pores and organic clusters. From the viewpoint of the microscope, therefore, reservoirs are taken as the aggregate of complex natural nano-materials. Reservoir research generally focuses on reservoir space, residual fluid occurrence and organic solid distribution.

Nano-characterization technology is used to analyze and test the material component, structure and property of nano-scale analysis objects, and research and develop testing tools and methods. It mainly consists of five aspects as follows.

1.1. Mineral composition

Mineral composition refers to the crystalline structure and component of reservoir mineral particles, and correspondingly the analysis devices are as follows. Scanning electron microscope (SEM) and atomic force microscope (AFM) are used to study appearance of mineral particles. X-ray diffraction analyzer (XRD) and high-resolution transmission electron microscope (TEM) are used to analyze the microcrystalline structures. And X-ray energy dispersive spectrometer (EDS), X-ray wave dispersive spectrometer (WDS), X-ray fluorescence spectrometer (XRF), X-ray photoelectron spectrometer (XPS), atomic absorption spectrophotometer (AAS) and inductively coupled plasma spectrometer (ICP) are used for element analysis. Among them, SEM, EDS, WDS, XRF and ICP have been extensively applied for petroleum geology research. For example, element analysis is used to discriminate mineral types and study the mineral transformation laws in the process of diagenesis and fluidization.

1.2. Micro-pore structure

In recent years, nano-characterization technology has been widely used to characterize micro-pore structures of reservoirs. Especially, the study on unconventional oil and gas reservoir has been developed great-leap-forward from the macroscope to the microscope and from the 2D to the 3D[10–13]. The corresponding analysis devices are as follows. 2D imaging devices include argon ion polishing-field emission scanning electron microscope (FESEM) and environmental scanning electron microscope (ESEM). 3D imaging devices include micrometer CT, nanometer CT and focused ion beam scanning electron microscope (FIB-SEM). 3D structure analysis technologies can be used to characterize the 3D spatial distribution of micrometer and nanometer pore throat structures after pore and matrix are extracted. The development of digital core technology promotes powerfully the research on the seepage mechanisms of unconventional oil and gas[14–17], and will predict the oil and gas development in the future.

1.3. Analysis on organic components

The organic matter in reservoirs contains solid organic matter (e.g., kerogen) and movable liquid organic matter (e.g., bitumen and crude oil). The components of organic matter are analyzed mainly by the following equipments. For example, gas chromatography (GC), liquid chromatography (LC) and mass spectrum (MS) are used to analyze element components. Ultraviolet-visible spectrum (UV), infrared spectrum (IR), Raman spectrum and nuclear magnetic resonance (NMR) are used to analyze molecular structures. Furthermore, ultramicro zone analysis methods will be introduced into petroleum industry, such as microzone infrared, scanning tunneling microscope (STM), ultrahigh-resolution fluorescence microscope and atom probe.

1.4. Petrophysical properties

Petrophysical property studies focus on characterizing and analyzing the physical and chemical properties of rocks by using various methods, technologies and equipments, such as mechanics, thermology, optics, electricity and magnetism. The petrophysical properties of reservoirs are investigated in the field of petroleum exploration and development. For example, the acoustics, electricity and thermology researches on rocks correspond to seismic logging, electric logging and thermal reservoir stimulation (e.g. in-situ combustion), respectively. So far, nanotechnology has not been applied extensively due to the scale restriction of exploitation objects. It is believed that in the near future, more and more physical property testing and research in the micro-scale will be carried out with the further development of unconventional oil and gas resource research.

1.5. In-situ characterization

As the studies are carried out further, the basic research on the accumulation and migration of oil and gas in reservoirs has been extended to the domain of microscopic dynamic characterization, and even the mechanism analysis of mole-