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Some key issues on the unconventional petroleum systems

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Abstract: Oil and gas currently still hold a leading role in the global energy mix. The recent drastic increase in unconventional oil and gas production contributes significantly to strike a balance between the global demand and supply of oil and gas. However, a range of important fundamental questions about the unconventional oil and gas resources have not been adequately answered. Little is known about the distribution and accumulation patterns, as well as the exploration and development characteristics of unconventional oil and gas. The current status of global oil and gas exploration was reviewed and four key theoretical issues regarding the unconventional oil and gas geology were identified: (1) the traditional concept and definition of "petroleum system" needs to be revisited. The concept of a "holistic-process accumulation" model of a "total petroleum system" in petroliferous basins was proposed to analyze the unconventional hydrocarbon accumulation mechanisms from four key aspects of quantitative studies on hydrocarbon generation–expulsion–migration–accumulation processes. (2) The second issue is related to fine-grained sedimentary system and sedimentary facies of tight reservoirs. Through analyzing the relationship between fine-grained sediments and unconventional hydrocarbon accumulation, three research integration areas were put forward. (3) The third issue is on the micro-nano pore system and fluid phase behavior in shales and tight reservoirs. Five aspects of micro-nano pore system were identified to focus on unconventional hydrocarbon research, and the characteristics of micro-nano pore development and fluid phase behavior in micro-nanopores were elucidated. (4) The fourth issue is related to unconventional hydrocarbon accumulation patterns and resource evaluation. Based on the characteristics of unconventional hydrocarbon accumulation, an evaluation system for unconventional hydrocarbon resources was established and optimized.

Key words: *energy consumption; unconventional hydrocarbons; exploration status; petroleum system; tight reservoirs; micro-nano pore system*

1 Introduction

Despite that global economic growth is slowing down, oil and gas still dominate the energy consumption mix, crude oil account for 32.9% of the global energy total consumption, and natural gas account for 23.8% of primary energy consumption (BPC, 2016). As degree of the conventional oil and gas exploration and development became more and more high, the unconventional oil and gas is regarded as a new resource to maintain long-term stability of oil and gas supplies. In the past several years, the main contribution to global oil and gas production growth comes from the United States and Canada instead of the OPEC countries. Indeed, the increment of oil and gas primarily came from the tight oil, shale gas and deep sea oil and gas of the

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United States, as well as the oil sands of Canada. In the next decade, the growth of global energy supply will mainly come from tight oil, shale gas and oil sands, and till 2030, the net growth of these three types of resources will account for 75% of the global energy supply (BPC, 2011).

Technological innovation and productivity gains have unlocked vast resources of the unconventional oil and gas. According to the prediction of Energy Information Administration (EIA), the global production of the unconventional gas is $822.7\times10^9 m^3$ in 2015, and will increase $2.48\times10^{12} m^3$ which accounts for 42% of global total natural gas production, including shale gas production of 1.7×10^{12} m^3, tight gas of 0.46×10^{12} m^3 and coalbed methane of 0.32×10^{12} m^3; the global production of the unconventional oil is 4.8×10^8t in 2015, and will increase 10×10^8t which accounts for 20% of global total crude oil production, including tight oil production of 5.1×10^8 t and oil sand oil of 3.4×10^8 t (EIA, 2016).

Although unconventional oil and gas have made a lot of progresses, many questions are still remained on the realistic significance of unconventional hydrocarbons and its sustainability as a viable fuel supply. It was reported in the Investor Journal that "the World Energy Outlook report of the International Energy Agency (IEA) gives us the impression that we are swimming in oil". Due to the development of the unconventional hydrocarbon resources, the once popular "peak oil" theory now merely becomes an irrelevant cultural concept (Hafez, 2013). A groundbreaking survey by the New York Times in 2011 revealed that "although the oil industry in the United States has adopted an extremely optimistic stance publically, it was skeptical about the potential of the shale gas in private" (Hafez, 2013). The assessment is not entirely irrelevant, and the exploration success rate of unconventional oil and gas with "continuous distribution" has not been all that satisfactory, while rapid decline of the production in the exploitation stage of shale gas is an indisputable fact. For example, the production of a shale gas well in the first year would fall by 60% to 90%. However, for the energy industry, the challenge is how to deal with the enormous transition at each stage by developing suitable conceptual geological models and enabling exploration and production (E & P) technology for unconventional oil and gas. In order to more effectively explore and exploit unconventional oil and gas resources and reduce E&P risk, one must carefully analyzes the generation, expulsion, migration and accumulation patterns of unconventional oil and gas, selects appropriate methods to evaluate unconventional oil and gas resources, and objectively assesses the potential of unconventional oil and gas resources. Accordingly, this study identified four important theoretical issues relating to unconventional oil and gas development, i.e., (1) reexamining the conventional "petroleum system" concept, (2) understanding the fine-grained sedimentary system and tight reservoir sedimentology, (3) elucidating the micro-nano pore system and fluid phase behavior in shale and tight reservoirs, (4) understanding the accumulation patterns of unconventional oil and gas and resource potential.

2 Strategic status and development restriction factor of unconventional oil and gas

2.1 Huge potential of unconventional oil and gas in global hydrocarbon exploration

2.1.1 Abundance and potential of unconventional oil and gas resources for exploration and development

Global unconventional oil and gas resources are extremely rich with huge potential for exploration and development. The total unconventional oil recoverable resources is up to 620×10^9 t, equivalent to the conventional oil resources, the unconventional gas recoverable resources estimated to be 4000×10^{12} m^3(BPC, 2016; CAPP, 2016; EIA, 2016). The ratio of unconventional and conventional oil and gas resources was 8:2 (Zou et al., 2015). In China, the unconventional oil resource is about 24×10^9 t, unconventional gas resource is about 100×10^{12} m^3, indicating a tremendous development potential (Li et al., 2012). Industrial development has been achieved for tight oil and gas, shale gas and coalbed methane as important supplement to conventional oil and gas, which will make more contributions to future oil and gas supply. Thus exploration and development of unconventional oil and gas has an important practical significance.

A decade ago, the inclusion of oil sands in Canada and heavy oil in South America led to an increase in global oil reserves by 140×10^9 t, representing the first expansion of global oil and gas resources. Tight oil and gas, shale gas, coalbed methane and other unconventional oil and gas resources have been greatly developed in the existing economic and technical conditions to show huge resource potential, resulting in the second expansion of global oil and gas resources. Taking the development of unconventional gas in the United States as an example, the development of shale gas and tight gas led to an increase in the proven gas reserves in the U.S. from 5.0121×10^{12} m^3 in 2002 to 6.9376×10^{12} m^3 in 2008 with a growth rate of 38% (BPC, 2013). Reserve growth greatly expands the resource potential. For example, unconventional gas resources are rich in China, with unconventional gas geologic resources of 140×10^{12} to 230×10^{12} m^3, and recoverable reserves of 35×10^{12} to 48×10^{12} m^3, accounting for about 75% of total gas resources (Jia et al., 2011a; Jia et al, 2011b). This has greatly expanded the total resources in China.

2.1.2 Steady increase of the proportion of unconventional oil and gas production

With the development of production technology, especially