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Comparison and Development Prospects of Coalbed Methane Technologies in China and Abroad

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ABSTRACT

Coalbed methane (CBM) possesses the triple attributes of being an energy source, a greenhouse gas, and a mine disaster gas, making it a critical target for increasing reserves and production of unconventional natural gas, as well as for coal mine safety governance. This paper systematically reviews the current status of CBM development technologies in the United States, Australia, Canada, and China through literature review and case analysis. It focuses on comparing the technological path differences among these countries in terms of resource endowment, well type selection, reservoir stimulation, and drainage systems. Research indicates that North America and Australia have formed mature models centered on vertical wells or multi-seam co-production, primarily targeting shallow, medium-to-low rank, and high-permeability coal seams. Under the conditions of high-rank, low-permeability, and deep-buried coal seams, China has developed characteristic technologies such as "geology-engineering integration," horizontal well volume fracturing, and full life-cycle drainage, achieving breakthroughs in the medium-shallow high-rank coals of the Qinshui Basin and the deep coal rock gas of the Ordos Basin. Future efforts should continuously focus on sweet spot evaluation and construction, deep fracturing and intelligent drainage, green and low-carbon development, and policy synergy to enhance the safety, economic viability, and strategic support capacity of the CBM industry.

KEYWORDS

Coalbed methane; Deep coal rock gas; Geology-engineering integration; Horizontal well fracturing; International comparison.

1. INTRODUCTION

Coalbed methane is an unconventional natural gas, primarily composed of methane, that occurs in coal seams and adjacent rock layers. On one hand, it serves as a clean energy source supplementing conventional natural gas supplies; on the other hand, it is a significant greenhouse gas and mine disaster gas. Its efficient development and utilization hold triple significance for energy security, emission reduction, and coal mine safety. Existing studies indicate that China's CBM resources at depths shallower than 2000m amount to 30.05×10^{12} m^3, while the potential for deep CBM at depths greater than 1500m is even larger, making it an important replacement field for increasing natural gas reserves and production since the 14th Five-Year Plan period [1,2]. Globally, CBM resources are widely distributed in major coal-bearing basins in North America, Australia, and China. However, significant differences in coal rank, burial depth, pressure systems, and permeability among different countries determine that there is no universal paradigm for development paths.

Taking the United States, Australia, Canada, and China as subjects, this paper combines literature review and case analysis to conduct a comparison from three levels: resource endowment, engineering technology, and industrial path. First, it reviews the current status of CBM development technologies in major producing countries. Second, it summarizes China's key breakthroughs in the medium-shallow high-rank coals of the Qinshui Basin and the deep coal rock gas field of the Ordos Basin. Third, it analyzes the differences between China and other countries from the perspectives of resource adaptation and technological iteration, thereby proposing future development suggestions. The core question addressed in this paper is not "who started earlier," but "what kind of resource conditions shaped what kind of technological route," which is also the key to understanding the independent innovation logic of China's CBM technology.

2. INTERNATIONAL COALBED METHANE DEVELOPMENT TECHNOLOGY STATUS

2.1. United States

The United States is the earliest country to achieve modern commercial CBM development, having formed a relatively mature industrial system as early as the 1980s. Its development targets are generally characterized by medium-low rank, shallow, and high-permeability coal seams. Coal reservoir permeability is typically higher than 5×10^{-3} μm², and mostly features normal to over-pressure systems. Consequently, a classic technical route dominated by "vertical wells + depressurization via water drainage" was established [3,4]. In favorable blocks, the daily production of a single well can exceed 1×10^4 m³. The US experience demonstrates that when coal seams are shallow, natural fractures are well-developed, and seepage conditions are favorable, commercial production can be achieved with low-complexity vertical well development. However, with the advancement of the shale gas revolution and the shift in oil and gas strategic focus, the priority of CBM among unconventional natural gases in the US has significantly declined, and it is no longer the most crucial incremental field.

2.2. Australia

CBM development in Australia mainly relies on coal-bearing basins such as the Surat Basin and the Bowen Basin. Its typical reservoirs feature medium-low coal ranks, multiple thin layers stacked together, and relatively good permeability. In particular, the Walloon coal measures in the Surat Basin exhibit geological conditions suitable for large-scale drainage [5]. Compared to the US, the key to Australia's technological advancement lies not only in single-well technology but also in the systematic supporting of multi-seam drainage, intensive well group deployment, surface gathering and transportation, and produced water treatment. Relying on multi-seam drainage and full-industry-chain synergy, Australia has achieved large-scale CBM development, leading global CBM production in recent summaries. Its path indicates that in multi-seam stacked and well-connected coal measures, integrated field development is more decisive than single-well extreme yield enhancement.

2.3. Canada

Canadian CBM development is relatively close to that of the US in terms of geological conditions and early technology, mainly focusing on shallow CBM development. The core technology is vertical well depressurization drainage and conventional reservoir stimulation. Its resources are primarily concentrated in coal-bearing areas such as Alberta, where the resource base remains substantial. However, in recent years, Canada's unconventional natural gas increments have mainly come from shale gas and tight gas, leading to a relative decline in the importance of CBM and a corresponding shift in development focus [4]. Therefore, the Canadian case shows that even if CBM resources exist, as long as other unconventional resources have an advantage in economic viability and production potential, CBM may transition from a primary resource to a supplementary one.

2.4. Summary of Technical Characteristics

In summary, the successful experiences of the US, Australia, and Canada are essentially built on the foundation of "matching resource endowment with engineering simplification": shallow, medium-low rank, and higher permeability reservoirs make it easier to achieve commercial development through vertical wells or multi-seam co-production. The foreign technical route highlights "adaptive development," meaning achieving large-scale production with low engineering complexity. This contrasts sharply with China's long-term confrontation with high-rank, low-permeability, low-pressure, and even deep-buried coal seams, providing a clear reference point for the comparative study in this paper.

3. COALBED METHANE DEVELOPMENT TECHNOLOGY STATUS IN CHINA

3.1. Industrial Development Stage

Summarizing recent reviews and industrial evolution nodes, this paper categorizes China's CBM development into five stages: preliminary exploration, technology introduction and trial development, pilot test and technical breakthrough, medium-shallow CBM commercial development and scale production, and deep coal rock gas exploration breakthrough and beneficial development [1, 2, 6]. This evolutionary process shows that China's CBM industry is not a simple replica of the North American path but has achieved a technological system reconstruction by continuously responding to complex geological conditions. Since the 14th Five-Year Plan, deep coal rock gas has been elevated to a strategic replacement resource for unconventional natural gas, marking a shift in the industrial driving force from policy and investment stimulation to theoretical recognition breakthroughs and key technological innovation.

3.2. Medium-Shallow CBM Development Technology: A Case Study of the Qinshui Basin

The Qinshui Basin is one of the most representative areas for high-rank CBM development in China. Its coal reservoirs are dominated by anthracite and have long faced unfavorable conditions such as low permeability, low pressure, and low saturation. High-rank CBM was once considered a "development forbidden zone". To tackle this challenge, China has gradually formed a medium-shallow development concept centered on geology-engineering integration: emphasizing the fine characterization of coal seam structure, gas content, and stress fields in geological understanding, and emphasizing optimized well locations, optimized trajectories, and synchronized reservoir stimulation and fine drainage in engineering implementation. Research on the Zhengzhuang block shows that the No. 3 and No. 15 coal seams exhibit significant differences in gas content, stress direction, and coal body structure; therefore, efficient development must be achieved through customized drilling systems and reservoir stimulation designs [7].

At the technical level, the Qinshui Basin has formed a combined technical system of "optimal well placement - high quality and fast drilling - high energy fracturing - efficient drainage." Studies by Li Guishan et al. show that the optimized horizontal well drilling system in the Zhengzhuang block achieves a coal seam drilling rate of 99%, with the daily gas production of well ZH-L36 reaching 4×10^4 m^3/d after fracturing [8]. Zhu Qingzhong et al., starting from the occurrence and output laws of gas and water in high-rank coal, proposed a channeling-based efficient development theory centered on "dredging + guiding," emphasizing that production capacity should be enhanced through full communication between the reservoir and the wellbore [9]. On this basis, recent engineering practices have further developed a "stepped pressure-controlled channeling" fracturing concept, which involves dredging micro-fractures first, then gradually increasing pressure to construct a complex fracture network, thereby improving the mobilization degree of low-permeability high-rank coal reservoirs. Public reports in 2026 show that the daily production of high-rank CBM horizontal wells in the Zhengzhuang block has stably exceeded 3×10^4 m^3 and maintained production for over a hundred days, setting a new record for domestic medium-shallow CBM single-well production.

3.3. Revolutionary Breakthrough in Deep CBM / Deep Coal Rock Gas: A Case Study of the Ordos Basin

The breakthrough in deep CBM represents a major paradigm shift in China's CBM development. Traditional understanding usually held that the deeper the coal seam, the poorer the gas content, the less developed the fractures, and the weaker the developability. However, recent practices in the eastern margin of the Ordos Basin in China indicate that deep coal seams not only still possess good gas preservation conditions but also exhibit a significant increase in free gas contribution. The development target has extended from the traditional shallow adsorbed gas-dominated "coalbed methane" to "deep coal rock gas" characterized by both adsorbed and free gas. This cognitive breakthrough holds important methodological significance: "deep" does not necessarily mean a development forbidden zone; the key lies in re-understanding the accumulation mechanism, preservation conditions, and engineering modifiability.

Centered on the development of deep coal rock gas, China has gradually established a technical system focusing on sweet spot evaluation, optimized and fast horizontal well drilling and completion, volume/fracture network fracturing, and full life-cycle drainage. Research on the Daning-Jixian block shows that deep coal seams typically feature "large burial depth, high pressure, high gas content, high saturation, and low permeability," requiring geological area selection, well pattern deployment, fracture network modification, and drainage systems to be optimized as a whole [7]. Relevant research and field practices indicate that the eastern margin of the Ordos Basin has gradually entered the stage of "scale exploration + pilot testing" since 2019, with the daily gas production of vertical wells exceeding 2×10^4 m^3 and horizontal wells exceeding 10×10^4 m^3 [6]. The Daning-Jixian block has formed a three-stage full life-cycle drainage process, achieving substitution in early self-flowing, mid-term plunger lift, and late-stage pressurized gas lift, improving the stable production capacity of deep CBM [10].

More importantly, the deep coal rock gas breakthrough has changed the growth logic of China's CBM industry. Zhou Lihong et al. pointed out that the deep coal rock gas breakthrough enabled China to build the world's first deep CBM field, marking the emergence of a new strategic replacement resource in the unconventional natural gas field. As of February 2025, public reports show that the cumulative production of China's first successfully developed deep coal rock gas field has exceeded 3 billion cubic meters, indicating that deep coal rock gas has shifted from a theoretical breakthrough to verifiable scaled production practices. Consequently, China's CBM development is moving from a new stage of "medium-shallow supplementary development" to "deep incremental dominance".

3.4. Other Technical Progress

In addition to medium-shallow high-rank coal and deep coal rock gas, China's CBM technology also exhibits significant synergistic and green trends. First, the coordinated development of coal and CBM emphasizes "integrated gas extraction and coal mining" and "surface-underground stereoscopic development," with the core being coordinating time sequence, spatial layout, and mutual influence to reduce resource waste and enhance coal mine safety assurance [11]. Second, research on CBM co-production in multi-seam areas continues to deepen. Current understanding holds that pressure system differences, permeability differences, and reservoir damage control are key to determining co-production effects. Homogenized reservoir stimulation, separate pressure system development, and fine drainage are important directions to improve co-production efficiency [12]. Third, under the background of the "dual carbon" goal, UCG-CBM-CCUS integration has become a frontier direction. The synergy of underground coal gasification, CBM development, and CO_2 capture, utilization, and storage is considered an important path for the future green utilization of deep coal resources, though it is generally still in the stage of technological perfection and demonstration advancement [13,14]. Furthermore, for fragmented, soft, and low-permeability tectonic coals, technologies such as roof horizontal well cross-measure fracturing and outburst mitigation coordinated extraction are also forming adaptive routes.

3.5. Comparison of Chinese and Foreign Technologies and Analysis of Development Characteristics

Based on the aforementioned literature, the CBM development paths of China and foreign countries can be summarized in Table 1 below.

Table 1. Comparison of CBM Development Characteristics between China and Major Producing Countries

Country	Primary Resource Endowment	Dominant Technology	Typical Development Characteristics	Development Path
United States	Medium-low rank, shallow, high permeability	Vertical well + depressurization drainage	High single-well production, high maturity	Early start, declining attention in recent years
Australia	Multi-thin layer, shallow, capable of multi-seam drainage	Multi-seam drainage + intensive well pattern	High degree of scaling	Relying on multi-seam co-production and full industry chain support
Canada	Mainly shallow, favorable conditions	Mainly vertical well drainage	Technical path similar to the US	Gradual shift in development focus
China (Medium-Shallow)	High-rank coal, low permeability, low pressure, low saturation	Horizontal well + channeling/volume fracturing + fine drainage	Single-well breakthrough of 30,000 m^3/day	Iterative upgrade centered on adapting to complex geology
China (Deep)	Deep burial, low permeability, high pressure, high gas content, increased free gas contribution	Horizontal well + fracture network fracturing + full life-cycle drainage	Multi-well breakthrough of 100,000 m^3/day	Dual revolution in theoretical understanding and engineering technology

From the comparison results, the essence of the differences between China and foreign countries lies not in China being a "latecomer," but in its more complex resource endowment and more difficult development targets. North America and Australia mainly face favorable reservoirs that are shallow, highly permeable, and drainable, so their technical routes lean towards "engineering simplification + scale replication." Conversely, China has long faced high-rank, low-permeability, low-pressure, and deep coal seams, necessitating breakthroughs through high-complexity technologies such as geology-engineering integration, horizontal wells, volume fracturing, and fine drainage. In other words, the global significance of China's CBM technology lies not only in production growth but also in providing a new path for unconventional natural gas development under complex geological conditions, distinct from the North American model.

4. SUMMARY

Facing the future, China's CBM industry needs to move from "breakthrough point success" to "large-scale, low-cost, and green success." First, geology-engineering integration should be further deepened, shifting from "sweet spot prediction" to "sweet spot construction," integrating resource evaluation, well deployment, fracturing design, and drainage systems into full life-cycle synergistic optimization. Second, sustained original technological breakthroughs should be promoted, focusing on key issues such as the accumulation mechanism of deep coal rock gas, fracture network formation and propping mechanisms, efficient drainage under high water-gas ratios and sand production conditions, intelligent lifting, and digital management. Third, green and low-carbon requirements should be embedded throughout the entire development process, promoting the synergistic development of UCG-CBM-CCUS, CO_2 displacement stimulation, low-emission gathering, and produced water resource utilization. Fourth, the management of mining rights, block exit mechanisms, demonstration zone policies, and industry chain supporting facilities should be improved to reduce the constraints of resource fragmentation and institutional friction on development efficiency. Fifth, a dual-wheel drive of medium-shallow stable production and deep incremental production should be implemented to promote a synchronized leap in production and output value, enabling CBM to play a more stable strategic role in natural gas security, coal mine safety, and carbon emission reduction.

Overall, there is no single universally applicable path for CBM development technology; its core is always the matching of resource endowment and engineering technology. The United States, Australia, and Canada have demonstrated mature development models for shallow, high-permeability coal seams, while China has forged an independent innovation-led development path under complex conditions of high-rank, low-permeability, and deep coal seams. In particular, the breakthroughs in the medium-shallow high-rank coals of the Qinshui Basin and the deep coal rock gas of the Ordos Basin demonstrate that China has not only moved from following to running alongside but also possesses a certain leading significance in the development of complex coal reservoirs. With the in-depth advancement of the energy transition, CBM is expected to play an even more important role in the synergy of increasing reserves and production of unconventional natural gas, coal mine safety governance, and pollution reduction and carbon mitigation.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

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