

关于中国页岩气勘探开发工作的思考

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摘要 随着全球经济发展对油气资源需求量的不断增长以及常规油气资源勘探开发难度的不断加大,页岩气等非常规油气资源在油气供给中的比例将日益增加。近年来北美地区页岩气快速发展,主要得益于其优越的地质地表条件,得益于水平井及水力压裂等核心工程技术的进步,得益于高效组织降低了成本,得益于政策的大力扶持。中国海相古生界页岩具有分布面积广、厚度大、有机质及脆性矿物含量高、有利成藏条件;同时,与北美页岩相比,中国南方海相页岩也存在沉积时代老、埋藏深、成熟度高、保存条件差、地表复杂等不利条件。鉴于此,中国在勘探开发页岩气过程中需要加强有利区块评价优选,提高工程技术水平、加大应用力度,努力降低勘探开发成本,并积极寻求国家政策的支持。

关键词 中国 页岩气 成藏机理 勘探思路 开发技术 有利条件 不利因素

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页岩气是指主体位于暗色泥页岩或高碳泥页岩中,以吸附或游离状态为主要存在方式的天然气聚集^[1]。在页岩气藏中,天然气赋存于细粒的粉砂岩、细砂岩、粉砂质泥岩及石灰岩、白云岩或不同颗粒大小的混合岩性中,是天然气生成之后在源岩层段内就近聚集的结果,表现为典型的“原地”成藏模式^[2]。

近年来,随着社会对清洁能源需求的不断扩大、天然气价格的不断上涨、对页岩气成藏条件认识的不断深化、钻井工艺的不断改进,页岩气勘探开发正由北美向全球扩展。页岩气在非常规天然气中异军突起,成为全球非常规油气资源勘探开发的新亮点。加快页岩气资源勘探开发,已经成为世界页岩气资源大国的共同选择。

1 美国页岩气快速发展的有利条件

美国含页岩气盆地共有22个,可采资源量为 $16.9 \times 10^{12} \text{ m}^3$,投入商业开发的主要有Fayetteville、Haynesville和Marcellus等盆地^[3]。美国页岩气藏分布于海相古生代地层,大面积连续成藏;以吸附、溶解

和游离3种状态赋存,主要为吸附气与游离气;来源于生物成因类型、热成因和混合成因等3种成因类型,以热成因为主。

美国页岩气勘探始于1981年,至2009年底,完钻页岩气井 4.2×10^4 口,2009年页岩气产量 $900 \times 10^8 \text{ m}^3$,预计2015年可达到 $2800 \times 10^8 \text{ m}^3$ 。

1.1 美国页岩气成藏条件优越

1) 地质背景好,页岩广泛分布、产状平缓、后期断层与褶皱不发育,埋藏深度适中。以Fort Worth盆地为例,其总体处于一个稳定的构造地质背景,Barnett页岩广泛稳定分布,具有开发潜力的面积为 $1.036 \times 10^4 \text{ km}^2$,核心区面积达到 4000 km^2 ^[4],埋深范围主要介于1000~3500m之间。

2) 页岩有机质丰度高,演化程度适中, $TOC > 2\%$,干酪根类型为混合型, $R_o > 1.1\%$;核心区 TOC 介于 $2\% \sim 7\%$, R_o 介于 $1.1\% \sim 1.7\%$ 。

3) 页岩层内有机质微孔隙、原生孔隙以及无机矿物之间的粒间孔发育,总孔隙度一般介于 $4\% \sim 12\%$,构成了游离气储集空间,是页岩气井早期高产的基础。

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4) 具有良好的区域盖层。页岩气储层一般超压, 区域盖层缺失将导致地层压力降低, 可能造成页岩气解吸和散失。另外, 盖层缺失容易使页岩气储层与水体沟通, 在页岩气储层内产生地下水径流, 对页岩气储气具有较强烈的溶蚀作用。

1.2 关键技术的突破推动页岩气快速发展

美国页岩气勘探开发历程证明, 进行规模开发是页岩气工业化生产的关键^[5]。由于页岩气单井产量低, 为了提高效益, 需要增加单井产量, 为了获得较高的总产量需要增加生产井数, 两项需求促进了相应工程技术的发展。

1.2.1 水平井部署和钻井技术

在水平井的部署时, 应考虑水平段在空间上的均匀分布, 尽量使水平段避开断层, 垂直于天然裂缝带延伸, 因而需要优选水平段入靶位置、延伸方向。目前美国采用“餐叉式”丛式井组, 每个井组一般 5~10 口水平井, 水平段长 1 000~1 500 m, 两水平井之间井距 150 m。水平井钻井工艺核心技术在于地质导向, 目前规模应用最先进高效的旋转地质导向系统 Power-Drive Archer, 可较好地控制井眼轨迹, 造斜能力达到 17°/30 m, 进尺 5 000 m 的水平井只需要 280 h。

1.2.2 压裂改造技术

压裂改造包括压裂设计、压裂施工以及压后评价 3 个阶段。压裂设计过程中, 优选射孔段、合适粒度和硬度的支撑剂, 采取多段分簇、大规模的施工方式, 对页岩进行体积改造, 目前, 单井压裂规模已达到“千方砂、万方液”。

应用微地震技术实时进行压裂效果检测, 掌握压裂缝的延展方向、空间几何形态和改造效果, 明确主力产层段。

1.3 规模效应及高效组织降低了施工成本

页岩气勘探开发采取批量作业的方式, 一个地区一次部署井位超过 100 口, 通过新技术的规模应用、生产组织的合理高效运作, 使得页岩气开发成本逐年下降, 尤其是 2009 年上半年, 每米进尺完井与压裂改造费用由 1 014 美元降至 709 美元, 为页岩气的快速发

展打开了出路。

1.4 优惠政策为页岩气快速发展提供了良好的发展环境

美国政府 1980 年颁布的《能源意外获利法》第 29 条税款规定: 1980—1992 年间钻探的非常规天然气井生产出的可享受税收补贴政策(页岩气为 3.5 美分/ m^3); 同时得克萨斯州对页岩气开发免收生产税。这些措施为美国页岩气的发展创造了良好的环境。

2 中美页岩气成藏条件对比

我国海相古生界页岩分布面积广、厚度大, 有机质含量与成熟度较高, 具备页岩气成藏条件。南方地区元古界—古生界发育 6 套海相页岩地层, 其中志留系龙马溪组和寒武系筇竹寺组页岩有机质含量高、厚度大, 页岩气资源潜力大。目前中国页岩气勘探开发区域主要位于我国南方海相地区^[6-8]。

我国南方地区具有与美国东部盆地相似的页岩气成藏地质条件和构造演化历史, 均属于古生代海相沉积盆地; 沉积环境为深水相沉积、浅—深水陆棚相; 页岩的 $TOC > 2\%$, 为富有机质页岩, 有机质类型为腐泥—混合型; 页岩脆性矿物含量较高, 石英、长石、方解石等脆性矿物总含量大于 40%^[9-14]。应该看到, 中国和美国页岩气成藏条件也存在较大的差异性(表 1), 主要表现在以下几个方面:

1) 中国南方海相页岩沉积时代比美国老, 主要以早古生代寒武纪和志留纪为主。目前美国页岩气开发的 5 个主要盆地中, 页岩的形成时代以晚古生代泥盆纪、密西西比纪和中生代白垩纪为主。

2) 中国下古生界海相页岩 R_o 值一般介于 1.1%~4.6% 之间, 目前已演化至高—过成熟阶段, 页岩有机质演化程度偏高。美国主要页岩气储层 R_o 值一般介于 0.4%~2.5% 之间, 正处于生气高峰期。

3) 美国目前已开发的页岩气藏埋深范围主要在 1 000~3 500 m 之间; 中国南方海相页岩埋深小于 3 000 m 的范围较小, 部分页岩储层埋深可超过 5 000 m, 埋藏深度较大。

表 1 中国南方下古生界海相页岩与美国页岩气成藏条件对比表

地区	时代	沉积相	地化特征		脆性矿物含量	埋深/m	保存条件	地表
			TOC	R_o				
美国	D、C	深水陆棚	2%~14%	1.1%~3.5%	40%~70%	1 000~3 500	构造稳定 地层平缓	平坦
四川盆地	-C、S	深水陆棚	2%~8%	2.5%~4.0%	37%~80%	1 500~5 000	多期改造 构造复杂	山地
中国南方	-C、S	深水陆棚	2%~8%	2%~4%	37%~80%	200~5 000	断层发育	

4) 美国大陆总体为一个稳定地台, 以海相沉积为主, 页岩气藏构造条件较为简单, 页岩气储层大面积连续分布, 储集条件较好; 中国陆地总体以陆相沉积为主, 可供勘探面积较小, 仅在古生界扬子地块、华北地区和塔里木盆地存在较为广泛的海相页岩沉积。

5) 中国下古生界海相页岩后期改造比美国强烈, 尤其是南方的扬子地块, 盆地周缘页岩地层抬升出露, 盆地内部页岩遭受断层切割, 气体大量散失, 保存条件不利。

6) 地表条件差异大, 美国 Barnett 页岩主要分布于美国地势较为平坦的地区; 而中国目前认为页岩气成藏最有利的南方海相地区, 多处于地形复杂的山区。

3 中国发展页岩气需要注意的几个问题

通过分析我国页岩气成藏条件和资源潜力, 笔者认为我国具备发展页岩气的基本条件, 但在具体工作中需要注意 4 方面的问题:

1) 要加强有利区块评价优选工作。我国页岩气勘探工作刚刚起步, 需要借鉴美国页岩气选区评价经验, 结合我国页岩气成藏地质特点, 在有利目标优选过程中, 充分考虑储层分布面积、埋藏深度、地势和水源等问题。井位部署过程中应避开构造变动强烈的褶皱区, 重点考虑大型宽缓的构造斜坡区。重点层系主要考虑下古生界寒武系和志留系页岩。我国陆相盆地页岩分布广泛, 在对海相盆地页岩气进行评价的同时兼顾陆相盆地页岩气地质研究工作。

2) 在工程技术方面要提高技术水平、加大应用力度。具体来说, 要加强测井解释和综合评价力度, 加强多种学科的综合应用、多种信息的综合分析评价, 测井资料的综合解释应用, 不断提高研究水平; 要加大水平井应用力度, 提高部署水平、施工水平、钻井速度及综合效益; 要规模应用水平井分段压裂技术, 根据水平段内岩性、物性及应力的变化, 分段设计相应的施工参数进行压裂, 最终在水平井段形成多条相互独立的人工裂缝系统, 改善近井地带渗流条件, 提高单井产量; 要尽快开展压裂监测工作, 引进相关技术, 实时研究裂缝扩展规律, 及时采取有效措施控制裂缝的扩展形态, 保证压裂质量, 评价压裂效果, 改进压裂措施以及优化后期部署方案。

3) 要努力降低勘探开发成本。目前, 我国页岩气相关作业成本过高, 严重制约了页岩气产业的发展; 必须通过规模部署、提速增效、精细组织等合理有效的手段, 降低页岩气勘探开发成本, 只有实现效益开发, 页岩气生产才有出路。

4) 要积极寻求国家政策的支持。借鉴美国的做法, 积极争取页岩气在税收、财政补贴等方面的优惠政策, 为推动页岩气的发展创造良好的外部环境, 调动能源企业参与发展页岩气的积极性。

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ABSTRACTS AND AUTHORS

Main solution ways to speed up shale gas exploration and development in China

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NATUR. GAS IND. VOLUME 31, ISSUE 5, pp. 1-5, 5/25/2011. (ISSN 1000-0976; In Chinese)

Abstract: At present, shale gas recovery and utilization has become the focus in the global hydrocarbon exploration and development. To accelerate the process of shale gas exploration, development and utilization will help China to change its hydrocarbon resource pattern, even its whole energy structure, to mitigate the shortage of oil and gas resources, to ensure national energy security, and to promote the economic development. In view of this, this paper analyzes the shale gas resource potential and exploration status in China. Then, through a comparison with the successful experiences from American shale gas exploration and development, the following problems in this case in China are pointed out: the shale gas resources have not yet been proven; the related policies and key technologies are in urgent need; the investors are extremely restricted by an inflexible investment system; and the pipeline infrastructure has not been completed. In the end of this paper, the main resolution ways to accelerate the process of shale gas recovery, exploitation, and utilization are presented: shale gas resources investigation should go first with the purpose of good planning and reasonable regulation; invite public bidding, multiple investment channels, and foreign cooperation should be encouraged; technical difficulties should be tackled; pipe networks should be completed; and environmental protection should be highly attended to.

Key words: China, shale gas, exploration and development, utilization, resolution, resource potential, problem, status

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A discussion on shale gas exploration and development in China

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Abstract: With the unceasingly growing need of global economic development for hydrocarbon resources and the accelerating difficulty in the exploration and development of oil and gas, unconventional hydrocarbon resources like shale gas, will account for an increasing proportion in oil and gas supplies. A rapid growth of North American shale gas development in recent years benefits mainly from geological and geographic conditions there, from significant advance in nuclear engineering technologies including horizontal well and hydraulic fracturing, etc., from the reduced cost due to high efficient organization and management, and also from the sup-

port by the government policies. In China, marine facies Paleozoic shale provides good conditions for shale gas pooling due to its wide area of distribution, huge thickness, high contents of organic matters and brittle minerals. Meanwhile, compared with North American shale, marine facies shale in the southern China has disadvantages like early deposition time, great buried depth, high maturity, bad preservation condition, and challenging ground environment. In view of this, the development of shale gas in China should focus on evaluating and selecting favorable target zones, improving the level of engineering techniques and promoting their wide application, trying every means to cut down the investment cost, and searching for support from government policies.

Key words: China, shale gas, pooling mechanism, exploration ideology, exploitation technology, favorable conditions, unfavorable factors

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Good lessons from the state level demonstration project of coalbed methane development: An overview of such high tech and commercial project in the southern Qinshui Basin

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Abstract: The high tech and commercial demonstration project of coalbed methane (CBM) gas exploitation and utilization in the southern Qinshui Basin is officially approved and implemented by National Development and Reform Commission in September 2004 as the first state level CBM gas development demonstration project. Responsible for such a project, China United Coalbed Methane Company Limited had worked on it for 5 years until the first stage of this project was completed in October 2009, when the annual CBM gas production of $1 \times 10^8 \text{ m}^3$ was obtained from a total of 150 wells. This success marks a leap forward in commercial development of CBM gas industry in China, setting a style for the rapid exploitation of CBM gas in the southern Qinshui Basin, thus accelerating the process of domestic CBM gas industrialization. Experiences learned from this demonstration project are concluded herein in this paper. 1) A modern management mode plays an effective role in the project organization and quality monitoring and control. 2) About 8 technical series have been developed worthy of being promoted and adaptable for the high rank coals in the southern Qinshui Basin, including 300 m \times 300 m well pattern arrangement, air drilling, hollow micro spheres low density cementing, water sand fracturing, nitrogen foam fracturing, per well gas gathered by fractional valve sets to the boosting station, fine stable controlling technologies of water drainage and gas production, characteristic analysis of anthracite coal bed production. 3) Pilot tests and field practices have been conducted on new materials and new equipment and two industry standards and two enterprise standards have been worked out and can be regarded as reference and models for domestic CBM gas development of vertical wells.

Key words: Qinshui Basin, south, coalbed gas field, ground development, industrialization, demonstration project, technical series, standards formulation

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