**DEVELOPMENT TRENDS OF UNCONVENTIONAL GAS RESOURCES IN CHINA**

Hongyan Wang, Guangjun Wang, Honglin Liu, Qun Zhao, Dexun Liu

*Langfang Branch Institute of the Research Institute of Petroleum Exploration and Development, Langfang 065007, China*

**Abstract**

Many countries in the world begin to attach great importance to the utilization of the unconventional gas. In some areas, tight gas, Coalbed methane (CBM) and shale gas have come into commercial development. The unconventional gas resources are very abundant in China. They developed rapidly in recent years, and some progress has been made. CBM in Qinshui Basin has been commercially developed successfully. Shale gas resource is also very abundant and has a good development prospect. Besides, the gas hydrate has a great potential in resources.

With scientific technologies advancing, many key technology handicaps will be overcome continuously. Reasonable and effective utilization of the unconventional gas can ensure the sustaining development of Chinese economy. There is estimated more than 12 trillion cubic meters, which takes 20% of the total production of the natural gas. The exploration and development of tight gas is mainly in the upper paleozoic gas reservoir, Xujiahe reservoir in Sichuan and jurassic-cretaceous reservoir in Kuche. Some progress has been made in CBM exploration and development in China and some mature technology series were established. Qinshui Basin is the main CBM development field in China. It is estimated that the rate is up to nearly 600 billion cubic meters per year. The industry scale has formed primarily. In the end of 11th Five-year (2010), 3 billion’s productivity is programmed to be built. Shale gas industry in china has just come into forth, and resources evaluation and exploration work has not opened out yet. The Sichan, Tarim, Ordos, Tuha, Songliao basins and the areas with carbonatite sediment in the South China have favorable conditions for shale gas accumulation and are very promising for exploration, so they are the important areas deserving people’s concern. Many seismic data analyzed, Bottom Simulating Reflectors (BSR) have been found in the slope of Okinawa trough, northern slope of the South Sea, trough of the South China Sea, south slope of Haisha Islands etc. the sedimentary samples of natural gas hydrate were acquired at the bottom of Shenhu area in South China Sea.

The geological conditions of unconventional gas are complex and different. Some technologies are juvenile and cannot fit for exploration & development. The output of a single well is low in permeable reservoir. So many theory and technology problems need to be solved, restricting the development step of unconventional gas in China. According to the major issues existing in unconventional gas studying, the major technology needs in the course of exploration and development are the five aspects: strengthening the basic research and developing different types technology of tight gas; optimizing CBM favorable target and expanding the scale of CBM exploration and development; effective technology of high step coal reservoir’s exploration and development; investigating the distribution of shale gas resources and finding out the major accumulating factors; carrying out the resources assessment of gas hydrate resources.

**Keywords:** Unconventional Gas; Tight Gas; Coalbed Methane; Shale Gas; Gas Hydrate

1 **Introduction**

At the background of the high develop speed of global economy and the request of increasing quantity of energy; the conventional hydrocarbon resources cannot meet the need of the social development. With the development of the exploration and exploitation of natural gas resources, the unconventional gas resources attract more and more attentions of people. It means mostly tight gas, coal-bed methane (CBM), shale gas, and natural gas hydrate and so on. The unconventional gas resources means the gas reservoirs whose reservoir-forming mechanism, occurrence state, distribution regularity, exploration and development measure and something else are different from the conventional gas resources. In order to increase the nature gas candidate reserves and the nature gas production, it is of immense strategic significance to make clear of the unconventional gas resources potential of China and expand the sphere of exploration.

2 **Analysis of Unconventional Gas Resources Potential**

2.1 **Tight Gas**

It has a wide area of the tight gas reservoir exploration in China. There are more than 10 basins such as Sichuan basin, Odors basin, Songliao basin, Bohai bay basin, Qaidam Basin, Tarim Basin, Junggar Basin and so on, which possess favorable geological conditions to form tight gas reservoir. It is predicted that the prospective gas resource is more than $1.2 \times 10^{12} \text{m}^3$ in China and is above 20% of the natural gas resources\(^1\). The tight gas resources are more abundant in Sichuan basin and Ordos basin.

The tight sandrock gas resource in Sichuan basin is relatively abundant, which proves a high potential for the development. According to the latest resources evaluation data, the natural gas resource is $1.8 \times 10^{12}-2.5 \times 10^{12} \text{m}^3$ in Chuanxi depression in Jurassic and upper Triassic. The current proved reservoir is $2.2 \times 10^8 \text{m}^3$ which is merely 10% of the resource\(^2\). Many gas fields were found such as Zhongba, Bingluoba, Jiulongshan, Hexingchang, Xinchang, Luodai, Xindu, Qiongxi, Mapeng gas field and so on. But there are still
a lot of resources which need to be found. Tight gas can be produced commercially in the Xujiahe formation of Suinan, Nanchong, Bajiaochang gas field in Central Sichuan Basin.

Gas fields such as Sulige, Yulin, Changbei, Daniudi were found in the north of Odors Basin. The Sulige gas field is of the geological gas reserves of 6025×10^8 m^3. It is the largest gas field found by far in China and has tremendous development potential.

2.2 Coal-bed Methane

Coal-bed gas resource in China is very abundant and gas reserve is the third of world next to Russia and Canada. From the newest statistics of resource assessment, the methane-bearing area is of 41.54×10^4 km^2 under the buried depth less than 2000 m in 45 coal-accumulating basins and the geological reserves is 36.8×10^13 m^3. There were 9 basins (Yili, Tuha, Odors, Diangjiangui, Junggar, Hailaer, Erlian and Qinshui) in China, each having geological reserves of more than 1×10^12 m^3. Their total reserve is 30.9×10^12 m^3, which is 84% of the total resources of China. The geological reserves under the buried depth less than 1000m are 14.3×10^12 m^3 and the recoverable resources are 6.3×10^12 m^3. The geological reserves buried from the depth of 1000m to 1500m are 10.6×10^12 m^3 and the recoverable resources are 4.6×10^11 m^3. The geological reserves buried from the depth of 1500m to 2000m are 11.9×10^12 m^3. Each of the part domains one third of the CBM reservoir reserves and the CBM reservoir under the buried depth less than 1000m is of the largest commercial value.

The CBM reservoirs in China have their unique complexities and specialties as stated below:

(1) The gas-bearing saturation and reservoir pressure of CBM reservoirs are low. The gas-bearing saturation is between 20% and 91%, average 45%, in the reservoir whose gas content is over 4m³/t in China. The reservoirs in northeast China have the highest value of gas-bearing saturation. Reservoirs in south China are higher. Reservoirs in north China and northwest China is the lowest. The coal reservoir of CBM is usually incompact, with pressure of reservoir less than 1, 0.3 as the minimum.

(2) Affected by multi-stage tectonic activities, coal formations easily break and tectonic coal develop. Coal fields in China are of complexity of geology structure, with some intensive late reformation, kinds of structural shapes, easily breaking, hard to develop. One fifth of that was tectonic coal mechanical, the strength of which is low, not easily to drilling.

(3) The resource of low rank coal is large, but the exploration theory is limited. It accounts 36% of the total gas resources in China. Because of less study of low rank coal, there is no large scale commercial exploitation of CBM field by far.

By 2007, there are 2500 boreholes drilled for CBM all over the country. Commercial production, vendition and utilization of CBM are preliminarily realized in Qinshui basin, Fuxin basin and Hancheng, south of Odors basin. Seven small scale CBM compact stations with the capacity 129.6×10^4 m^3 were constructed. Three CBM LPG stations with the capacity of 155×10^4 m^3 were built.

2.3 Shale Gas

Shale gas industry in china has just come into forth, and resources evaluation and exploration work has not opened out yet. The resource was forecasted by several domestic and overseas institutions, but the results are divergence in the different as show in Table 1. So a lot of exploration and research need to done in the development of Shale Gas in China.

The south China widely develops marine shale from Simian to mid-Triassic and the area of shale is 200×10^4 km^2. The shale of lower Cambrian, upper Ordovician-lower Silurian and the Permian distributes widely and it is the most favorable strata with large thickness, rich organic matter and high maturity. On the plane, Sichuan basin, the region of east Hubei and west Chongqing and lower Yangtze area are favorable region of forming shale gas reservoirs. Different scales of mud fracture reservoir or important oil & gas showing were found in lower Cambrian and lower Silurian in Sichuan basin.

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<tr>
<th>Region</th>
<th>Resource (tcm)</th>
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<td>100</td>
<td>Rogner</td>
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<td>Central Asia</td>
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<td>Kawata &amp; Fujita</td>
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<td>China (Main Region)</td>
<td>15–30</td>
<td>Colorado School of Mines</td>
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<td>China</td>
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The shale gas found in Weiyuan and Luzhoulong in Sichuan basin is predicted with resource potential 7×8×10^12 m^3. The shale in Odors, Tarim, Tuha and other regions are also of the conditions and basis to forming shale gas reservoirs.

In north and northeast China, shale gas reservoirs can develop at the bottom of primary oil producing beds or beneath these beds in Paleozoic, Mesozoic-paleozoic of Odors basin, Mesozoic of Songliao basin and Paleogene of shallow buried Bohai bay. The mudstones of these beds are buried from 50 to 2000m with average organic carbon 1.0%–2.0%, partial average value above 4.0% and largely vary maturity of organic matter.

In northwest China, constrained by the characteristics of the nowadays basins, shale in Mesozoic (Jurassic and Triassic) and shadow buried Paleozoic are favorable to develop with higher organic carbon and larger
variety of organic matter maturity. Though the ground condition of Tibetan plateau is poor, it is also favorable to forming shale gas reservoirs for its thickness of Mesozoic-Paleozoic, high average organic carbon and moderate maturity [6, 7].

2.4 Natural Gas Hydrate

Many seismic data were analyzed by the China Geological Survey et al. Bottom Simulating Reflectors (BSR) which indicates the existence of gas hydrate, have been found in the slop of Okinawa trough, northern slop of the South Sea, trough of the South China Sea, south slop of Hsisha Islands etc. Gas hydrate may exist in the South China Sea, the predicted resources of which are 65 billions tons of oil equivalents. The gas hydrate are surveyed in northern slop of the South Sea, cisa trough, Dongsha, Shenhuansha and southeast of Hainan with some BSR found, amplitude blanking zones, the region exists a lot of geochemical anomaly such as hydrocarbon anomaly of top gas characterized by abnormal concentrations of Cl and SO$_4^{2-}$ and abnormal of isotope. Some cold seep overflowing vents, carbonate crusts, microbial mat and bivalves were found. All the evidences above indicate that gas hydrate reservoirs exist in the South China Sea [8, 9].

East Sea is a back-arc basin of the trench-arc-basin system of West Pacific. It consists of East China Sea shelf, Okinawa trough, etc. According to the regional geological condition such as water depth, sea bottom temperature, heat flow value, deposit thickness, deposit velocity and total organic carbon, the Okinawa trough, especially southwestern slop, is suit for formation of gas hydrate. Some studies have reported the analysis and processing of geophysical data of Okinawa trough results in BSR found [10].

Moreover, the formation conditions and the ore prospecting of formation gas hydrate are better in the Qinghai-Tibet Plateau permafrost regions and the Northeast. Qiangtang Basin is one of the most promising to find Mine prospect area. The Qiangtang basin has the lowest annual average ground temperature, geothermal gradient minimum, relatively thick layer of frozen soil. There are a suitable temperature and pressure conditions and sufficient conditions for formation of gas hydrate. The significant high hydrocarbon anomaly is found in Qiangtang Basin, which may be associated with gas hydrate [11].

3 Current Development Status of Unconventional Gas Resources

3.1 Scale Development Technology Series of Tight Gas

In allusion to the facts of that the tight gas reservoirs characterized by low porosity and low permeability, high capillary pressure, formation pressure anomaly and high damage potential, the corresponding techniques improved in three terms which consist of gas reservoir description, reservoir protection techniques during drilling and completion and reservoir stimulation [12].

In terms of gas reservoir description, there are many technologies established, such as 2D&3D seismic prediction of formation pressure, 3D coherence technology, 2D&3D trace integration inverse technology and multi-well constrained seismic inverse technology. These technologies make reservoir description, determining prolific gas bearing zone and reservoir tracing come into truth [13].

In terms of reservoir protection techniques during drilling completion, based on selection of low damage mud systems, multifunctional shielding temporary plugging agent and lost circulation resistance technology, a temporary shielding plugging drilling-completion fluid technology for the sandstone reservoir protection is established [14].

In terms of reservoir stimulation, in order to solve the problem of the breakdown of low temperature hydraulic fracturing gelled fluids, the shallow reservoirs’ hydraulic fracturing technology characterized by low lead volume moderate, small discharge volume, high proppant ration was established. In order to improve fracturing fluid backflow, the middle-deep reservoirs’ commingled fracturing or separate layer fracturing technology which is characterized by big sand volume, big discharge volume and moderate proppant ration was formed.

Some technological progress was made, but in terms of producing degree and recovery percent of reserves of tight sandstone gas is far lower than that of mid-high permeability sandstone and carbonate rock(fig. 1), being still in a relatively young development phase.

![Graph](image_url)

Fig 1Comparison of tight gas and other types of gas reservoirs in producing degree and recovery percent
3.2 Preliminary Development Technology Series of CBM

After tackling the key development technique problems of CBM reservoir, the CBM reservoir exploration and development technique series are now figured out with the CBM reservoir geophysical exploration, the CBM reservoir drilling and completion and the CBM reservoir yield increasing techniques. The development of high-metamorphous anthracite acquired essential achievements by years of techniques tackling.

In terms of the CBM reservoirs geophysical exploration, based on the 3-dimension 3-components seismic exploration of Huainan coalfield, prediction methods of coal formation thickness, fracture development and gas accumulation location of CBM are preliminarily established. Furthermore, with the utilization of longitudinal wave azimuth and AVO theory, fracture azimuth and density prediction has been confirmed.

In terms of the CBM reservoir drilling and completion, aimed at the exploitation of the CBM in high-metamorphous low permeable anthracite reservoirs, the pinnate horizontal multilateral well technique was carried out and designed the scheme.

In terms of the CBM reservoir drilling and completion, in order to develop high metamorphous low permeability anthracite reservoirs, the pinnate horizontal multilateral well technique was proposed, and the practical scheme was designed.

In terms of the CBM yield increasing techniques, the fracture extended law and hydraulic fracture diagnosing method were established at the basis of the statistics and analysis of the hydraulic fracturing wells. In addition, producing test acquired achievement with individual-well CO₂ injection and individual-well CBM production [15, 16].

3.3 Preliminary Study of Shale Gas

Though relative studies have already carried out, there is no commercial exploitation of shale gas in China. In terms of exploration, mud fracture gas reservoir was developed. Lots of experiments were accumulated on drilling and completion technique of clay shale fracture oil & gas reservoir, protection of production zone and stimulation of low permeability reservoir. Drilling in the branch horizontal well and fracturing technology was gasped.

3.4 Steady Basis Study of Gas Hydrate

In 2007, the sedimentary samples of natural gas hydrate were successfully acquired at the bottom of Shenhua sea area in South China Sea by Chinese Geological Bureau. This marks that after American, Japan and India, China is the 4th country that systematically carried out the survey of gas hydrate and acquired original place gas hydrate samples.

In recent years, China enhances the study of gas hydrate. Institutions represented by Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences (GIECCAS) established a few simulation apparatus for the development of gas hydrate. The GIECCAS developed 1D and 2D experimental simulation system and successfully synthesized the gas hydrate. China University of Petroleum (East China) designed a 2D experimental apparatus which can simulate the natural gas hydrate formation and dissociation in porous media. Besides, Institute of Marine Geology In Qingdao developed a similar system.

In addition, scientists of China probed preliminarily into the “three high” seismic data processing methods which aimed at identification of gas hydrate. The forward gas hydrate simulation and integrated identification for sedimentary reservoirs of the gas hydrate have been carried out. And the feasibility of multi-wave seismic exploration is studied for gas hydrate in South China Sea and East China Sea [17-19].

3.5 CNPC Strongly Develop Unconventional Natural Gas Resources

3.5.1 Tight Gas

Since 2000, cumulative proved reserves of tight sandstone gas of China National Petroleum Corporation (CNPC) has gotten 1.42×10⁸ m³, average 1800×10⁸ m³ per year. In 2007, the production of tight gas is 72×10⁸ m³ which is 15% of the total natural gas production. So the growth trend is full of power. By 2020, the predicted production is 500×10⁸ m³, which will be 30% of the total gas production.

In term of different geologic features of gas reservoirs, development schemas of different types of tight gas reservoirs are formed. For the lenticular reservoir, the schema of rolling development, vertical well completion, downhole choke and interwell replacement technology operated smoothly in Suliige gas field. In Xujiahe gas field, horizontal and vertical well fracturing and fixed production operation is currently applied. For the bedded sand reservoir, the schema of dual branch horizontal well, pressure fixed production, single well high production at the beginning and inter-well replace technique is applied to Changbei gas field. In the south of Yulin gas field, vertical well fracturing and fixed production operation technique is developed. So the primary development schema is composed of gas reservoirs description, optimization of well location, completion technology of horizontal well and vertical well and the corresponding reservoir protection technique. For the block gas reservoir, the schema is composed of precise reservoir description, perforation optimization, fracturing at long well and well infilling.

3.5.2 CBM

CNPC have got resources quantity of 1.43×10¹² m³ of CBM. By 2007, 600 wells were drilled, 50 branch horizontal wells contained and the production of CBM is 3×10⁸ m³. By 2010 the production is predicted to reach 15×10⁸ m³. With the technical research and development, CNPC have owned low cost straight borehole drilling technology, air drilling technology in the CBM reservoirs, wire line coring technology and rapid desorption technology, the evaluation technology of the production of the CBM reservoirs and clean
hydraulic fracturing technology for CBM well. Contemporarily, an advanced CBM laboratory has been established by CNPC which have owned the national patents of hydraulic fracturing for CBM well, wire line coring and rapid desorption of CBM.

3.5.3 Shale Gas
In recent years, China National Petroleum Corporation has conducted a preliminary study on the shale gas resources in China, which indicates that marine shale in Southern of China may be the main gas-rich region, with the basic conditions of shale gas reservoir. In addition, China National Petroleum Corporation has established many laboratory equipments, such as coefficient of diffusion determinator, specific surface-pore determinator, total organic carbon analyzer and shale gas adsorption determinator, and is able to test and analysis of shale gas.

3.5.4 Gas Hydrate
In 2005-2008, China National Petroleum Corporation has carried out two-dimensional, three-dimensional seismic exploration in the South China Sea, and a special treatment with hydrates. The BSR indicate in some areas are found and a set of research ideas and methods on hydrate are also summed up.

4 Technology Prospect on Exploration and Development of Unconventional Natural Gas Resources
The geological conditions of unconventional gas are complex and different. Some technologies are juvenility and cannot fit for exploration & development. The output of a single well is low in permeable reservoir. So many theory and technology problems need to be solved, restricting the development step of unconventional gas in China.

Unconventional natural gas resources have the characteristics of complex reservoir conditions, dense reservoir, strongly heterogeneity. Tight gas reservoirs have the characteristics of low porosity, low permeability, high capillary pressure, abnormal formation pressure, high-damage potential and so on. Coal-bed methane reservoirs have the characteristics of strong heterogeneity, low permeability, low reservoir pressure, low gas saturation. At present, the development of unconventional natural gas is mainly refer to the experience of conventional natural gas, and has not yet formed a unique technology. The formation mechanism of the cracks in fracturing stimulation is not yet clear, needed to further study. In addition, there are problems with the high failure rate of drilling in the branches well.

According to the major issues existing in unconventional gas studying, the major technology needs in the course of exploration and development are the five aspects as follows:

1) Strengthening the basic research and developping different types technology of tight gas
   For weakness of basic geology engineering research of tight gas, lack of effective means to prevent and release the damage in stimulation transformation, the reservoir protection technology should be continued to improve. The application of special process well and horizontal well technology should be emphasized. The adaptability of modification technology should be vigorously improved. So the integrated technique series for different types of tight gas will be established.

2) Optimizing CBM favorable target and expanding the scale of CBM exploration and development
   In view of the low level of exploration for CBM, there is not a deep profound study on gas accumulation, distribution pattern, and forecasting of high-yield-rich region, preparation for the favorable target areas, so constituency evaluation should be carried out. It is the future important task to provide more favorable exploration targets.

3) Effective technology of high step coal reservoir’s exploration and development
   There are not perfect exploratory development technologies and equipments for coal-bed methane, so advanced production technology should be introduced and developed: multilateral horizontal well and well drilling technology, fracture detection technology, efficient drainage management technology, and physics simulation technology of CBM and so on.

4) Investigating the distribution of shale gas resources and finding out the major accumulating factors
   The forming mechanism of shale gas in China is particular. It has the characteristics of various reservoir conditions, universal development, broad distribution and resources large and so on. The large amount of data given by drilling is favor to reduce the cost of shale gas exploration. However, there is no assured data in China; so the distribution of resources and host factors accumulation should be investigated and identified.

5) Carrying out the resources assessment of gas hydrate resources
   BSR have been found in the slop of northern slop of the South Sea, East China Sea, etc. But the distribution, buried depth, size and resources of gas hydrate is not clear yet. So resource assessment of gas hydrate should be done.

For the exploratory development of the unconventional natural gas resources, we should constantly explore the area of enrichment and high production, and carry on pilot tests, summing the regularly and reforming the existing technology, bringing forth innovation theory, solving the major technical problems.
References


