



Research Article

# Integration and scale application of shale gas exploration and development engineering technologies in Sichuan and Chongqing areas<sup>☆,☆☆</sup>

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## Abstract

Based on 8 years' exploration and production since the spud in of the first shale gas well in the Changning–Weiyuan national demonstration zone in the Sichuan Basin in 2009, great progress and all-sided development have been achieved in shale gas exploration and development engineering technologies in China. In order to promote scale shale gas development efficiently with high benefits in Sichuan and Chongqing areas, it is of great significance to summarize in time the optimized and integrated support technologies of shale gas exploration and development engineering. And the following research results were obtained. First, 10 principal technology series at the domestic leading level in shale gas well drilling and completion engineering are formed and completed, providing a technical support for a drastic increase of shale gas production. Second, volumetric fracturing support technologies from design to laboratory experiment evaluation and to real time monitoring of fracturing networks based on borehole seismic data are developed, ensuring the implementation effects of shale gas stimulation schemes. Third, simultaneous operation modes are innovatively established, such as drilling–fracturing, drilling–production & transportation and fracturing–production & transportation, and pad arrangement is optimized so that batch, modularized, programmed and integrated operation is realized and the commissioning schedule of shale gas wells is sped up greatly. Fourth, six series of environmental protection and energy saving technologies for shale gas development are developed, and consequently clean and energy saving production of shale gas is realized. Fifth, a technological system with a high-precision 3D seismic prospecting technology as the base is established to provide a basis for the realization of “transparent” gas reservoirs. Sixth, ground gathering technologies are optimized and intellectual and digital management of gas reservoir production and transportation is realized. It is concluded that these support technologies for shale gas exploration and development engineering provide an effective support for the increase of shale gas production of the Changning–Weiyuan shale gas national demonstration zone and they play a guiding and demonstrating role in technological progress and managerial innovation.

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**Keywords:** Sichuan Basin; Changning–Weiyuan shale gas national demonstration zone; Engineering series; Drilling–fracturing; Drilling–production & transportation; Fracturing–production & transportation; Large-scale benefit

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Shale gas, as an unconventional natural gas, extensively distributes with abundant reserves in the world. China's technically recoverable resources of shale gas are about  $21.8 \times 10^{12} \text{ m}^3$ , which shows considerable resource and social values. The Sichuan Basin is the most advantageous shale gas exploration and development area in China [1–3]. CNPC Chuanqing Drilling Engineering Company (hereinafter referred to as CDEC) has a complete business chain from geological evaluation to drilling and transportation operations, and has been the first to start shale gas engineering services

since 2009 when the first shale gas well in China was drilled. Later, CDEC achieved a number of domestic top records, and undertook the construction of Weiyuan national shale gas demonstration zone. It participated in the formulation of special standards (29 sets) with regard to shale gas. CDEC has formed 41 shale gas technologies in six categories integrating services and development, which help accelerate the construction of shale gas productivity in the Sichuan–Chongqing area. At present, CDEC has completed the drilling of shale gas wells with a total footage of nearly  $100 \times 10^4$  m, and fracturing of 180 wells. In the Weiyuan well area, the cumulative production of shale gas is about  $13 \times 10^8$  m<sup>3</sup>.

### 1. Characteristics and difficulties of shale gas reservoir development

- 1) Shale gas reservoir is a self-generated and self-preserved gas reservoir. Natural gas is accumulated in shale in an adsorbed or free state. The reserve calculation method for conventional gas reservoir is not applicable to shale gas. Moreover, the calculation of shale matrix porosity, the determination of gas content and the accurate evaluation of fracture system are extremely difficult. Therefore, shale gas resources are difficult to evaluate accurately.
- 2) There are many factors affecting the productivity of shale gas wells, including geologic conditions, reservoir physical property, horizontal section length and hole position, fracturing mode, and flowback control. These complex factors raise high requirements for development scheme.
- 3) Horizontal wells are the key to achieving profits of shale gas development, by increasing the seepage area, and enhancing the single well production. However, most favorable layers are thin, which makes it difficult to control the horizontal well trajectory. Meanwhile, single well productivity is affected by the length of favorable layer penetrated, and the well completion has higher requirements for the smoothness of wellbore trajectory.
- 4) Reservoir stimulation is critical to shale gas development. Unlike conventional wells, shale gas wells have no natural productivity, so it is necessary to perform large-scale sand fracturing to obtain production, and the fracturing effect directly affects the yield. How to optimize fracturing and improve the complexity of artificial networks are difficulties to be addressed in shale gas development.
- 5) Shale gas production cycle directly impacts commercial development. How to shorten the well construction time, put the well into production rapidly, and realize efficiency increase are the only approach to achieving commercial development, which definitely puts forward higher requirements for shale gas development engineering technology.
- 6) Shale gas well is characterized by fast production decline and long-term fracturing fluid flowback, making the well in a status with both gas and water. It is essential

to adopt economic and effective engineering methods to ensure stable yield with low pressure and low production, and improve recovery. Thus, pertinent and economical approaches of water drainage and gas recovery are required.

- 7) Environmental protection faces high stress. The Sichuan–Chongqing shale gas fields are located in the environmentally sensitive areas and ecological fragile zones. According to the New Environmental Protection Law of the PRC issued in 2015, drilling/complete wastes, flowback fluid, waste drilling fluid and oil-based cuttings are the biggest environmental problems in drilling operations.

### 2. Featured engineering technologies

The Sichuan Basin is currently the key region of shale gas exploration and development in China, and also the most successful region. It has undergone pilot tests and rapid development stages. It has gradually entered into the stage of scale development. By centering around “cost-effective and efficient development”, strengthening and integrating domestic technical researches, introducing advanced and applicable technologies from other countries, and highlighting “localization, autonomization and integration”, 41 featured engineering technologies have been developed in 6 aspects as follows:

- (1) Optimized and fast horizontal well drilling/completion technologies: geo-engineering integrated design, casing program optimization, 3D-to-2D trajectory transition, high efficiency PDC bit optimization and design manufacturing, gas drilling, oil- and water-based drilling fluids, steering tools, geo-engineering integration steering, memorized special well logging, and horizontal well cementing;
- (2) Matching volumetric fracturing technologies: Volumetric fracturing optimization design, volumetric fracturing evaluation, complex fracture network fracturing, fracturing fluids, high efficiency sectional tools, cluster perforation & special perforation, coiled tubing drilling, and micro-seismic monitoring;
- (3) Factory-like operation technologies: double-rig batch drilling, synchronous operation of drilling and fracturing, zipper-type (synchronous) fracturing, and platform layout optimization;
- (4) Clean production technologies: sewage diversion technology, cuttings not landing, drilling fluid recovery, reduction of emission and noise generated by electricity instead of oil, thermal grinding on oil-based cuttings, and produced water treatment;
- (5) Gas reservoir-related geological engineering technologies: high-resolution seismic acquisition and processing, logging interpretation, resource quick evaluation, integrated geological–engineering modeling, well location optimization and shale gas reservoir dynamic analysis;

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