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High-efficiency fracturing technology and application on CBM horizontal wells in Qinshui Basin

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Abstract: L-type horizontal well has become a new well type for CBM development in Qinshui Basin, And the staged fracturing technique of horizontal well is the key technology to improve gas production of single well for coalbed gas .At present, the main fracturing technology of horizontal well is the fracturing technology of tubing carrying a packer at the bottom, and daily gas production of it exceed 10000 cubic meters in Zhengzhuang with ultra-low permeability .And the average daily gas production of a well is more than 6000 cubic meters .In recent years, we have gradually explored different fracturing technologies ,containing plug-perforation joint fracturing ,coiled tubing fracturing and staged fracturing of spray gun with expanding diameter. Taking the L-type horizontal wells of the casing fracturing in Qinnan as the research object, the adaptability analysis and the evaluation of development effect of four fracturing technologies, including the fracturing of common tubing carrying a packer at the bottom ,the fracturing of spray gun with expanding diameter, plug-perforation joint fracturing and coiled tubing fracturing, are carried out .The analysis results show that the fracturing technology of tubing carrying a single packer at the bottom has the advantages of simplicity ,low price and good effect on development, which can be used as the main technology of the L-type horizontal wells of the casing fracturing.

1. Introduction

As an efficient technology of low-permeability coal reservoir, horizontal well is applied to exploit coal bed gas in a wide-ranging area. By changing the original structure state and original stress distribution of coal seam, horizontal well can effectively improve the fracture system of coal reservoir and expand the desorption area of drainage and depressuring .In the early production of coalbed gas, the barefoot multi-lateral horizontal well was widely used . Although the technology has achieved good development effect in the high-permeability area and shallow coal seam in the south of Fanzhuang, the barefoot wellbore is easy to collapse and be blocked, which leads to the pollution in coal seams .So it is unable to dredge wellbore and implement stimulation transforming, which restricts growth of single well production .In view of the existing problems of barefoot multi-lateral horizontal wells, U-type horizontal wells, tree-structured horizontal wells, horizontal wells of roof fracturing and other technologies have been applied , and some achievements have been achieved in some blocks, while due to the limitation of geological conditions and economic effects, it scarcely meets the needs of large-scale application . The screen pipe horizontal wells and casing horizontal wells were explored and tested later, which basically solved the problems of barefoot multi-lateral horizontal wells, realized the goal of reentry, maintenance and transformation, and achieved great field application effect ^[1-5].



In this paper, the L-type casing horizontal wells in Fanzhuang-Zhengzhuang block in the south of Qinshui Basin is taken as the research object, the analysis of the adaptability of different fracturing technologies for casing horizontal wells is carried out. And the production effects is evaluated, so as to provide technical guidance and empirical support for the future development of CBM.

2. Geological outline

Qinshui Basin is located in the southeast of Shanxi Province. It is a structural tectonic composite basin formed since Mesozoic. Fanzhuang-Zhengzhuang block is located in the southeast of the basin. And the main CBM reservoir in the area is 3[#] coal seam of Permian Shanxi formation. The burial depth of coal seam is 300-1200m, and the thickness is stable, and is generally 5-7m. In this area, broad and gentle folds trending in the NE and NS directions developed, and anticlines alternate with synclines, and the major principal stress is mainly NE approaches. The gas content is high on the whole, and is generally 14-30m³/t, with an average of 20 m³/t. Affected by the structure and hydrodynamic conditions, the gas content is low in some parts. The coal seam permeability of evaluation wells in the area is 0.001-0.91 mD, with an average of 0.27 mD, and the permeability gradually decreases with the increase of burial depth. The coal body structure is complex, and there are primary structure coal, cataclastic coal, fragmented coal and mylonite coal, and primary coal and cataclastic coal is the main coal in general, and cataclastic coal and mylonite coal are mainly developed near the roof and floor of coal seam and gangue.

3. The staged fracturing design of L-type casing fracturing horizontal well

In order to solve the problems of effective development in low-permeability area and worse exploitation effect caused by low permeability and broken coal body structure, L-type horizontal wells began to apply casing fracturing in 2016. The L-type casing fracturing horizontal well is similar to the L-type screen pipe fracturing horizontal well. Generally, there is only a project well and a main branch. The footage of main branch in coal seam is about 800-1000m. Through fracturing, the control area of single well is larger than that of single screen pipe horizontal well, which is 0.02-0.04km². The second-interval wellbore structure is adopted for drilling, and the casing in the coal seam is not cemented. After completion, staged perforation fracturing is implemented (see Figure 1) to improve the effect of reservoir stimulation.

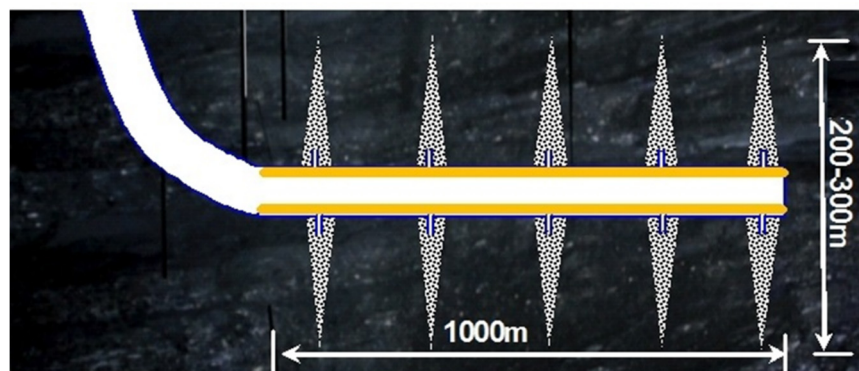


Figure 1. A fracturing model of L-type casing fracturing horizontal well

L-type casing fracturing horizontal well can effectively solve the problems of low producing degree of reserves in low permeability reservoir reserves and vertical wells fracturing in structural coal developed area. The advantages of the technology are simple, controllable, having good stability of wellbore, and it is easy to reconstruct in the future, except that it also enhance the permeability of coal bed. The staged fracturing technology of horizontal well is the key technology to improve the single well production of coalbed methane. The borehole trajectory of CBM horizontal well extends in the coal reservoir, expands the contact area between wellbore and coal reservoir, and increases the flowing channel of coalbed gas. Based on the effective communication between the wellbore of horizontal well and the coal seam, the multi-stage fracturing is carried out along the direction of the horizontal

section .The artificial fracture formed by staged fracturing of horizontal well can not only remove the pollution and blockage of drilling mud or cementing liquid near the well, but also increase the equivalent radius of "horizontal wellbore" .So that the coal seam can form a natural cleat / fracture network system with the borehole trajectory of horizontal well as the main channel and the system effectively dredges the well bore and coal reservoir through artificial fracture .And the system also increases the well control area, forms the accumulation effect of multi-stage desorption and seepage, effectively expands the pressure drop funnel range of coal reservoir, and improves the overall capacity of gas production [6-8].

The optimization design of staged fracturing of CBM horizontal well is the basis of effective development, and the optimization design of staged fracturing of CBM horizontal well and fracture parameters is the necessary prerequisite for staged fracturing, as shown in Table 1. The horizontal well is designed with short spacing and multiple sections (Figure 2), which is reasonably adjusted for high-quality coal seams.

Table 1. the optimization design of staged fracturing of CBM horizontal well

number	technical	parameter	objective
1	Optimizing transformation points	Perforation and fracturing of high-quality coal seam with natural gamma < 40api	Making long seam in high-quality coal seam to connect all levels of cleat and fracture
2	Optimizing segment spacing	The interval between sections is 80-100m	Forming effective communication of artificial fracture network
3	Staggered regional communication	Penetration coefficient (fracture length / well spacing) 0.5-0.8	Improving the overall the scope of transformation of the region and realizing coupling and dredging
4	Optimizing fracture conductivity	Fracture conductivity 15 ~ 22 m ² .cm	Increasing the conductivity of fracture and increasing the cumulative gas production of single well
5	Fast flowback	coal particle $U_{incipient\ motion}$ ≤fracturing fluid $U_{incipient\ motion}$ < quartz sand $U_{incipient\ motion}$	Blowouting immediately after fracturing of each section, and pressure drops quickly .Guiding high-pressure liquid and pulverized coal to vent quickly, and keeping cracks clean.

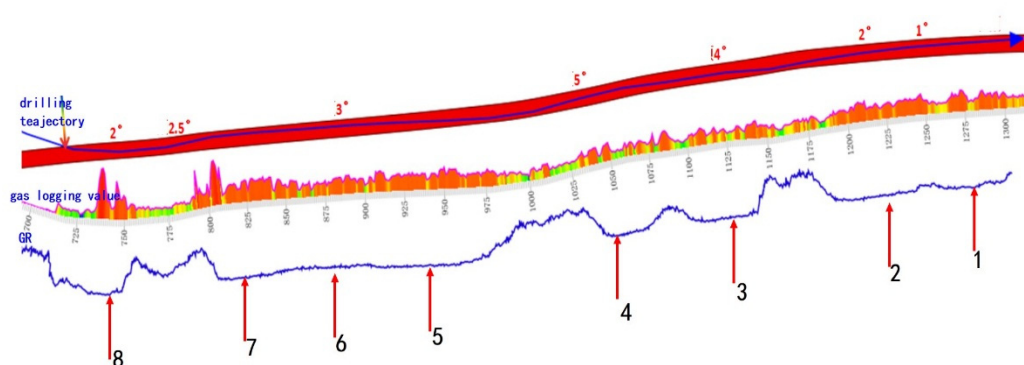


Figure 2. diagram of optimization of transformation points for staged fracturing of horizontal well

4. Staged fracturing technology of L-type casing fracturing horizontal well

4.1 common tubing carrying a packer at the bottom

Hydrojet fracturing is a new measure of stimulation. After the hydraulic perforation is completed through the nozzle, the jet continuously acts on the jet channel to form a pressurization, and the

formation is crushed after the pressure exceeds the fracturing pressure. At the same time, quartz sand and ceramics carried in the jet flow enter the formation to effectively support the fracture and complete the fracturing process. It is very important to keep a relatively low annulus pressure in the fracturing process. According to the operation theory of jet, on the inner surface of the boundary layer of the ejected fluid, the velocity is equal to the ejecting velocity, and on the outer surface, the velocity is equal to zero. So the velocity in the boundary layer gradually decreases from the ejecting velocity to zero from inside to outside. So the velocity of the jet boundary layer decreases, resulting in negative pressure. The liquid entering the jet boundary from around is driven into the formation by the jet, and the liquid in the boundary layer is reduced. At this time, the liquid should be added to the casing annulus to ensure the pressure and energy of the casing annulus^[9].

4.1.1 Pipe string structure

Pipe string structure: guiding bottom ball + hydraulic anchor + packer + hydraulic ejector + D73mm plain end oil well tubing (or tubing without coupling) + safety joint + D73mm plain end oil well tubing (or tubing without coupling) to wellhead (as shown in Figure 6).

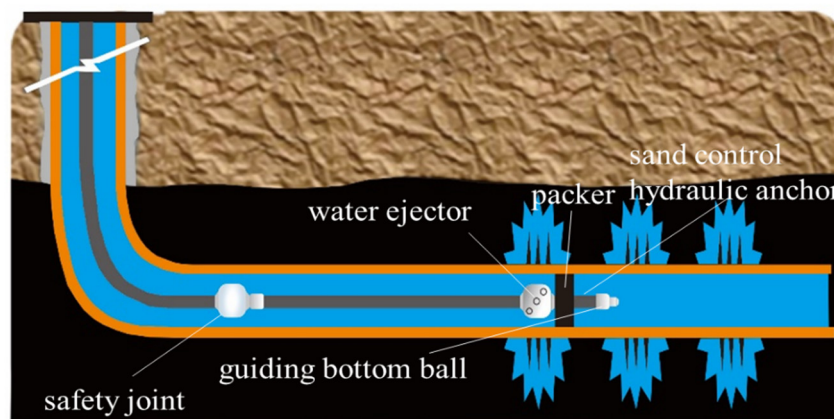


Figure 3. pipe string diagram of common tubing carrying a packer at the bottom

4.1.2 processes and parameters

Pipe string structure: drifting operation and flushing operation ;running the fracturing string ;installing the fracturing wellhead and carrying on pressure test ;injecting base fluid ;perforating the casing, fracturing through the annulus and supplying fluid through the tubing ;After the measurement of pressure drop, opening the casing valve to control the blowout ;After well flushing and blowout , if the conditions for string lifting were met, the wellhead will be removed ;lifting the string to the next setting point, and carry out the next process according to the pumping procedure.

Process parameters (per section)

- ① Fracturing fluid: active water (0.5% KCl) or clean water;
- ② The scope of fracturing fluid:400-800m³/Segment;
- ③ Proppant: quartz sand;
- ④ Proppant ratio:40/70 mesh:16/20 mesh=1:2;
- ⑤ The scope of proppant:40-80m³/Segment;
- ⑥ Average sand liquid ratio:8%;
- ⑦ Maximum flow rate: 6-7m³/min.

4.2 hydraulic jet integrated fracturing of spray gun with expanding diameter

In order to achieve the goals of rapid and efficient stimulation, reducing costs and improving production for large-scale staged fracturing of horizontal wells, the integrated staged fracturing tool of perforating and fracturing is studied. The integrated tool consists of three parts: spray gun with expanding diameter,

packer and release assembly, which are integrated into a whole, and one-time linkage is realized by injecting ball.

According to the number of sections, workers run all tools into the well, inject balls one by one, open the sliding sleeve of spray gun, set the packer of this section, and successively complete all processes such as perforation, hole cavity, external plugging between sections and sand fracturing. The technology has advantages of multi-function, high speed and all tool can be pulled out.

4.2.1 Pipe string structure

String structure: guiding bottom ball + spray gun with expanding diameter (without sliding sleeve) + staged integrated fracturing tool 1 + D88.9mm plain end oil well tubing + staged integrated fracturing tool 2 + D88.9mm plain end oil well tubing + staged integrated fracturing tool 3 + safety joint 1 + ... + staged integrated fracturing tool 5 + safety joint 2 + D88.9mm plain end oil well tubing to wellhead.

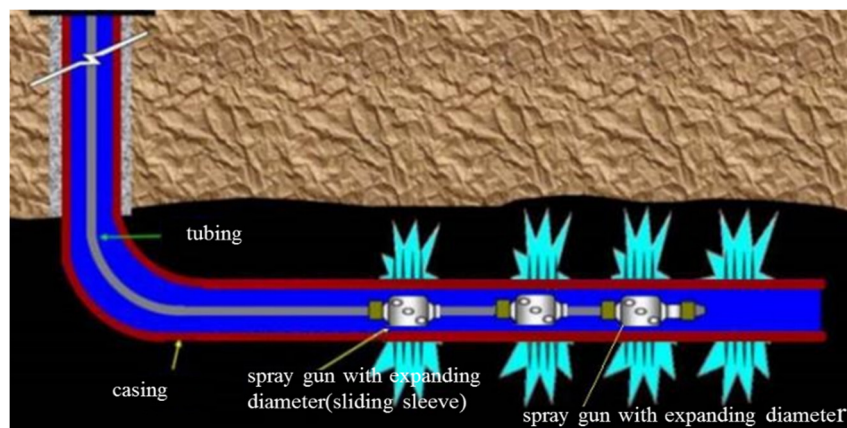


Figure 4. pipe string diagram of hydraulic jet integrated fracturing of spray gun with expanding diameter

4.2.2 processes and parameters

Process: drifting operation and flushing operation; running the fracturing string; installing the fracturing wellhead and carrying on pressure test; injecting base fluid; perforating the casing, fracturing through the tubing and supplying fluid through the annulus; in the process of fracturing, improving the flow rate step by step according to the nozzle expanding condition, and the blowout is carried out quickly after fracturing (Lifting the pipe string to next fracturing point) injecting ball to open the sliding sleeve of the next stage spray gun and beginning fracturing of next section.

Process parameters (per section)

- ① Fracturing fluid: active water (0.5% KCl) or clean water;
- ② The scope of fracturing fluid: 400-800m³/Segment;
- ③ Proppant: quartz sand;
- ④ Proppant ratio: 40/70 mesh: 16/20 mesh = 1:2;
- ⑤ The scope of proppant: 40-80m³/Segment;
- ⑥ Average sand liquid ratio: 8%;
- ⑦ Maximum flow rate: 6-7m³/min.

4.3 plug-perforation joint fracturing

In 2019, A new fracturing technology for CBM horizontal wells was introduced. By launching the perforating gun and bridge plug into the wellbore, the perforating gun and bridge plug are transported to the target formation. After the bridge plug is setting, the cable is lifted up, positioned step by step at different predetermined depths, and the perforating is carried out in turn. Finally, the cable and

perforating gun are pulled out, and then the hydraulic fracturing is carried out. In this way, the whole horizontal well sections can be perforated and fractured by stages. Bridge plug cluster perforation completion is one of the methods that are most frequently used for volume fracturing. And it can realize setting the packer of the lower section, perforating of upper section and fracturing of horizontal wells, realize multi-cluster fracturing of single section, casing fracturing with large flow rate and efficient fracturing. But it needs to launch bridge plug for many times and drill plug after fracturing.

4.3.1 Pipe string structure

String structure: guiding bottom ball + spray gun with expanding diameter (without sliding sleeve) + staged integrated fracturing tool + D88.9mm plain end oil well tubing + staged integrated fracturing tool + D88.9mm plain end oil well tubing + staged integrated fracturing tool + safety joint + ... + staged integrated fracturing tool + safety joint + D88.9mm plain end oil well tubing to wellhead.

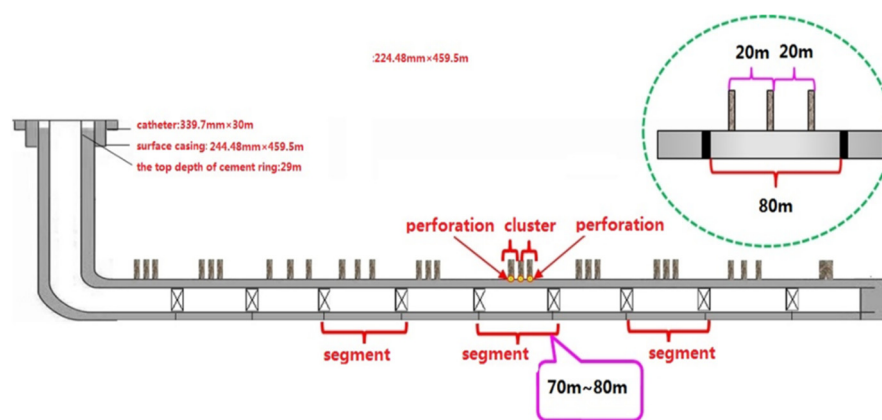


Figure 5. pipe string diagram of plug-perforation joint fracturing

4.3.2 processes and parameters

Process: drifting operation and flushing operation; running the fracturing string; installing the fracturing wellhead and carrying on pressure test; injecting base fluid; launching the perforating gun and bridge plug into the first section of wellbore, after the bridge plug is setted, lifting the perforating gun to the first cluster point; After the wellbore pressure test is qualified, perforating the casing by perforation of cable transmission; Putting out perforating gun and carrying out casing fracturing and beginning fracturing of nest section.

Process parameters (per section)

- ① Fracturing fluid: clean water / active water (0.5% KCl);
- ② The scope of fracturing fluid: 400-800m³/Segment;
- ③ Proppant: quartz sand;
- ④ Proppant ratio: 40/70 mesh: 16/20 mesh=1:2;
- ⑤ The scope of Proppant: 30-60m³/Segment;
- ⑥ Average sand ratio: 10-15%;
- ⑦ Maximum flow rate: 2-8m³/min.

4.4 coiled tubing fracturing

Coiled tubing staged fracturing is a safe and efficient fracturing technology, which is widely used in reservoir stimulation of conventional and unconventional oil and gas. For casing horizontal wells, coiled tubing with packer and spray gun at the bottle of string is drag to perforating and fracturing. A string can achieve unlimited staged fracturing, and can greatly shorten the operation time. Hydraulic injection can effectively reduce the initiation pressure of fracturing. fracturing through the annulus and supplying fluid through the tubing can meet the requirements of high flow rate fracturing operation, and the packer

at the bottom of tubing can improve the effect of sealing .Continuous fracturing under pressure can be carried out.

4.4.1 Pipe string structure

guiding bottom ball + porous surface tube + check valve + hydraulic anchor + packer + stabilizer + spray gun + stabilizer + missing device + external connector + coiled tubing to wellhead.

4.4.2 processes and parameters

Process: drifting operation and flushing operation; running the fracturing string ; performing the first stage of well; fracturing the first stage of well ;lifting the string to unseal ;perforating the second stage of well ;and so on ;pulling out the string and blowouting.

Process parameters (per section)

- ① Fracturing fluid: clean water/active water (0.5% KCl);
- ② The scope of fracturing fluid:650-800m³/Segment;
- ③ Proppant: quartz sand;
- ④ Proppant ratio:40/70 mesh:16/20 mesh=1:2;
- ⑤ The scope of Proppant:30-40m³/Segment;
- ⑥ Average sand ratio:7%;
- ⑦ Maximum flow rate:7.5m³/min.

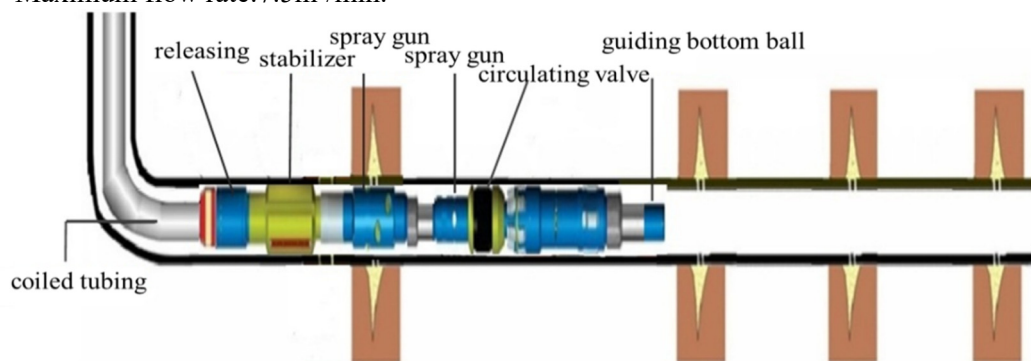


Figure 6. pipe string diagram of coiled tubing fracturing

4.5 analysis of advantages and disadvantages of different technologies

The advantages and disadvantages of different fracturing technologies are shown in Table 2

Table 2. advantages and disadvantages of different fracturing technologies

technology	advantage	disadvantage	application
Common tubing carrying a packer at the bottom	Simple ,low price, Staged blowout	long operating time and limited flow rate	Low flow rate, smooth borehole trajectory ,and horizontal segment within 1300 meters
spray gun with expanding diameter	Part of continuous fracturing with pressure ,long operating time ,and staged blowout	limited flow rate and the high risk of buried pipe string by sand	Smooth borehole trajectory , horizontal segment within 1300 meters
plug-perforation joint	continuous fracturing with pressure , high flow rate , long perforating time, clustering and short operating time	High price, sand slug, and the staged blowout is not allowed	Irregular borehole trajectory or long horizontal segment
Coiled tubing	Low fracturing pressure and short operating time	high price ,few holes and low density of holes ,It is difficult to stimulation in winter	smooth borehole trajectory , horizontal segment within 1300 meters, rapid fracturing

5. Fracturing effect of Horizontal wells

At present, 102 L-type casing fracturing horizontal wells have been put into operation, with an average gas production of 6520m³/d. Among them, the technology of common tubing carrying a packer at the bottom is widely used and the gas production is best. The average daily gas production of a well is 6700m³; There are only 4 wells were carried out plug-perforation joint fracturing, and the effect of gas production is the worst. The average daily gas production of a well is only 4300m³.

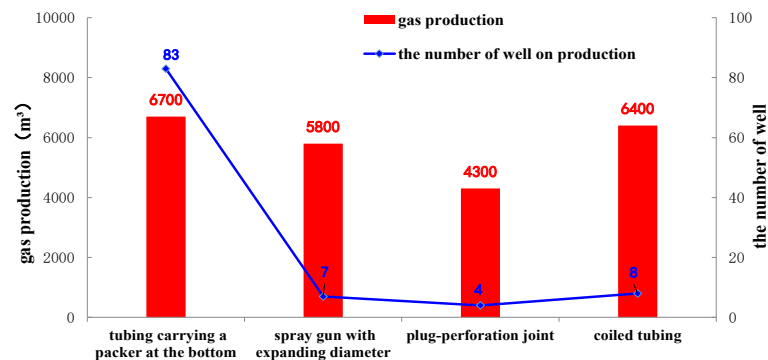


Figure 7. diagram of gas production of different technologies

6. Conclusion

1.L-type casing fracturing horizontal well is simple and controllable, with good stability of wellbore, which basically solves the problem of collapse of branch for barefoot multi-lateral horizontal well. And it realizes the goal of further stimulation in the future, and effectively improves the permeability of coal bed. The effect of site application is good, which is the key technology to improve the single well production of coalbed gas.

2.Considering economic cost, the fracturing technology of common tubing carrying a packer at the bottom is widely used, and the effect of gas production is the best. The technology of plug-perforation joint fracturing has little limitation for borehole trajectory and can realize the staged clustering fracturing. However, due to the high price and sand slug, its application is limited. The fracturing technology of spray gun with expanding diameter usually cause casing deformation and buried string by sand, which limit its application. For the technology of Coiled tubing fracturing, the operating time is short. But it is not easy to applied on a large scale due to its high price.

3.If the operating time of fracturing is considered, coiled tubing fracturing is preferred. If economy and blowout is considered, tubing carrying a packer at the bottom fracturing is preferred; If the demand of large flow rate is considered, plug-perforation joint fracturing is preferred.

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