

Optimization Design of Fracturing Parameters for Coalbed Methane Wells in Dafosi Mine Field

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Abstract

Being controlled by the gas content of the reservoir, the productivity of CBM well is also mainly determined by its engineering quality and the physical property of the reservoir. In Dafosi mine field, 22 vertical wells from the “26 + 1” CBM wells project that was implemented since 2014 showed great difference in productivity after fracturing construction. With the consistent geological condition of coal reservoirs, fracturing construction parameters are suggested as the priority factor that controlling the well productivity. In this study, being combined with historical production and geological data, an optimized designation of fracturing construction parameters was established based on systematically comparative analysis of construction parameters such as discharge, the total volume of fracturing fluid, the quality of sand, sand ratio, which provides engineering basis for further fracturing construction of CBM wells.

Keywords

Dafosi Mine Field, “26 + 1” CBM Wells Project, Fracturing Construction Parameters, Gas Production Effect

1. Introduction

The coalbed methane (CBM) resource is rich in China, but its exploration and development are relatively late. At present, the commercial development of CBM has been realized in high-rank coal areas of southern Qinshui basin and eastern Ordos basin [1] [2]. While, the exploration and development of CBM have not been developed in the low-rank coal area, in addition to some areas in the stage of commercialization of small scale.

Dafosi mine field is one of the state-owned key coal mines and located in the south of Binchang mining area of Jurassic in Shaanxi. The absolute and the rela-

tive gas emission are up to 155.49 and 23.40 m³/min respectively, which belong to high gas mine. Dafosi wells were taken underground drainage measures to prevent gas accident, and the gas drainage volume accounts for about 70% of the total gas emissions. It shows that high rate of gas extraction and the drainage effect are better. In order to further improve gas control effect and realize the effective utilization of CBM, the surface CBM development test has been carried out in Dafosi since 2009. The drainage data of several test wells shows that the low-rank coal in Dafosi mine field has better potential in gas production [3] [4]. The CBM wells constructed before 2014 in Dafosi mine field had obtained industrial gas flow. However, in the 26 + 1 CBM wells project (the ground coalbed methane project composed by 26 vertical wells and 1 multi-branched horizontal well) which was implemented since 2014, the productivity in most of the wells was low and unstable. The adverse reservoir reconstruction measures were blamed as the priority factors. Therefore, optimization design of fracturing parameters and proper reservoir stimulation are of practical significance for further CBM wells productivity [5] [6].

Fracturing construction is one of the most effective reservoir stimulation methods, of which hydraulic fracturing was most widely used [7] [8] [9]. Once the location of a well was adopted, the discharge, the total volume of fracturing fluid, the quality of sand and sand ratio were the key parameters that affect the fracturing construction [10] [11] [12]. Thus, the optimization of those parameters could help to improve the productivity of CBM in Dafosi mine field. In this study, an optimization design of fracturing construction was proposed based on statistical analysis of 24 vertical wells in which hydraulic fracturing was adopted in Dafosi mine field.

2. Currently Productivity of CBM Wells in Dafosi

Presently, all the 24 vertical wells (including 22 wells in “26 + 1” project and BCD-C-01, BCD-45) had obtained gas flow with hydraulic fracturing (**Table 1**). Among them, the hydraulic fracturing was performed on No.4 coalbed and upper No.4 coalbed (the upper coalbed of No.4) in BCD-45, BCD-105 and BCD-134. While in other wells, the hydraulic fracturing was only performed on No.4 coalbed. The averaged gas production of BCD-C01, BCD-128, BCD-134 and BCD-148 exceeded 1000 m³ per day, and the production in BCD-133 exceeded 2000 m³ per day. In contrast, the averaged gas production ranged from 200 to 700 m³ per day except the BCD-62, BCD-67, BCD-117, BCD-120, BCD-151 and BCD-153 wells which had been shut off. Generally, large majority of wells showed increasing productivity and well gas production potential.

3. Fracturing Construction Parameters of CBM

Hydraulic fracturing is one kind of fracturing construction methods that inject the fracturing fluid into wells by the high pressure introduced by ground equipment. The pressure would expand the fissures in coalbed. Then add the fracturing

Table 1. Gas production of the 24 vertical wells in Dafosi mine field.

| No. | Well | Production Q/m ³ | No. | Well | Production Q/m ³ |
|-----|---------|-----------------------------|-----|---------|-----------------------------|
| 1 | BCD-C01 | 3,233,752.49 | 13 | BCD-120 | 61,687.40 |
| 2 | BCD-45 | 463,556.84 | 14 | BCD-122 | 204,892.23 |
| 3 | BCD-62 | 3468.69 | 15 | BCD-128 | 636,225.46 |
| 4 | BCD-67 | 35,713.70 | 16 | BCD-131 | 465,635.11 |
| 5 | BCD-69 | 157,953.03 | 17 | BCD-132 | 539,127.94 |
| 6 | BCD-71 | 169,115.2 | 18 | BCD-133 | 1,643,606.58 |
| 7 | BCD-73 | 302,928.08 | 19 | BCD-134 | 1,300,276.17 |
| 8 | BCD-74 | 184,512.43 | 20 | BCD-135 | 265,586.12 |
| 9 | BCD-84 | 147,029.32 | 21 | BCD-148 | 796,871.34 |
| 10 | BCD-86 | 79,525.89 | 22 | BCD-150 | 162,326.95 |
| 11 | BCD-105 | 215,913.33 | 23 | BCD-151 | 393.20 |
| 12 | BCD-117 | 257.56 | 24 | BCD-153 | 4573.20 |

The data ended February 19, 2017.

propping agent, a seepage zone would be formed which connect the cracks in coalbed. Finally, the coalbed methane would desorb and exhaust via drainage and decompression.

3.1. Fracturing Fluid and Propping Agent

Currently, Reactive water fracturing fluid, foam fracturing fluid, gelled fracturing fluid and clean fracturing fluid are the most commonly fracturing fluid used in CBM wells (Table 2) [13] [14] [15]. In Dafosi mine, considering that the coalbed was characterized by high adsorption, seriously fracturing fluid loss, large scale and relative low pressure coefficient, it is applicable to choose the low-damaging and economical reactive water fracturing fluid. The reactive water fracturing fluid was composed by water, 1% KCl and 0.05% fungicide.

The loading strength and cost were the basic principles to choose propping agents. Since the closure pressure in coalbed of Dafosi mine was lower than 10 MPa, most of the propping agents could cover the requirements. In Dafosi mine, the quartz sand, with a compression strength of single particle 60 - 70 MPa, was taken as fracturing propping agents in all coalbed from the perspective of reducing cost and facilitating reactive water fracturing fluid transporting. The physicochemical property was shown in Table 3. During the fracturing construction, the propping agents included 20 - 40 mesh medium quartz sand and 16 - 20 mesh coarse quartz sand with the ratio 3:1. Pump the 20 - 40 mesh medium sand first, which show strong ability to penetrate coal seam, then pump the 16 - 20 mesh coarse sand to make sure that the fissures near the wells have high conductivity.

Table 2. The characteristics of different fracturing fluid.

| Types | Sand carrying ability | Fracture making ability | Damaging | Cost | Confection |
|---------------------------------|---|--|----------|------|--|
| Reactive water fracturing fluid | Weak low viscosity, transport propping agent rely on the displacement, usually short transport distance | Weak low viscosity, limited transformation scale; the vertical extension of fissures are difficult to control | Low | Low | East to confect and not limited by temperature |
| Gelled fracturing fluid | Strong transport propping agent relaying on viscosity and displacement, long transport distance | Strong high viscosity, the displacement, transformation scale and vertical extension of fissures are easy to control | High | High | Complex and high quality requirements |
| Clean fracturing fluid | Strong transport propping agent relaying on the viscosity and displacement, long transport distance | Strong high viscosity, the displacement, transformation scale and vertical extension of fissures are easy to control | Medium | High | High quality requirements and limited by temperature |
| Foam fracturing fluid | Strong transport propping agent relaying on the viscosity and displacement, long transport distance | Strong high viscosity, the displacement, transformation scale and vertical extension of fissures are easy to control | Low | High | Easy to confect, complicated construction procedure |

Table 3. Physicochemical property of quartz sand.

| Main mineral component | Apparent density g/cm ³ | Density g/cm ³ | Crushing rate 30 MPa | Turbidity |
|------------------------|------------------------------------|---------------------------|----------------------|-----------|
| SiO ₂ | 1.60 | 2.67 | 13.8% | 77.6 |

3.2. Construction Displacement, Quality of Sand, Averaged Sand Ratio and Construction Pressure

Plenty of natural cleavage system in coal seam made the CBM wells fracturing construction quite different from that in oil well. The prominent features were the giant loss low-efficiency of fracturing fluid. In order to increase efficiency, the fracturing construction displacement should be large enough. Thus, casing pipe with large construction displacement was adopted in Dafosi mine. The construction displacement in CBM wells was between 5 m³/min and 9 m³/min with most of them with the displacement 8 - 9 m³/min.

Considering that the coal seams in study area was in large thickness, shallow burial depth and good permeability, the fracturing quality of sand was adopted as the following: the quality of sand was set 7 m³/m for the target coal seam thickness more than 12 meters, 8 m³/m for thickness between 10 and 12 m, 9 m³/m for thickness between 8 and 10 m and 10 m³/m for thickness less than 8 m. It is worth mentioning that the BCD-71 and BCD-135 was taken secondary fracturing due to the rough appeared in the first fracturing construction. Finally, all the wells finished the designed sand fracturing except BCD-71, BCD-74 and BCD-84. According to the construction data, the averaged sand ratio was kept in 10% to 13%.

According to the fracturing construction data of 24 vertical wells for 27 coal-beds in Dafosi mine field, generally, the normal fracturing pressure was lower than 20 MPa, and Shut-in pressure was lower than 15 MPa. 1 h after the termi-

nation of pumping, the wellhead pressure in CBM wells decreased directly to zero or sharply to zero in several hours, which indicated a high permeability in coal seams in study area and favorable conditions for the diffusion and migration for CBM. However, the high permeability would enhance the loss in fracturing fluid and show negative effects on fracturing construction. Therefore, 1 or 2 fine sand slugs were performed during preflush construction stage. The slugs would not only decrease the loss of fracturing fluid but also improve the efficiency of fissures making and sand carrying, and decrease the possibility of sand plugging during fracturing operation.

4. Optimization of Fracturing Parameters in CBM Wells

4.1. Influence Factors of Fracturing Construction in CBM Wells

Generally, the fracturing construction effect was controlled by two categories: the coal reservoirs parameters and the fracturing construction parameters [16]. The coal reservoirs parameters included the gas content, permeability, reservoir pressure, gas saturation, coal rank and depositional environment, etc [17]. The fracturing construction parameters included the types of fracturing fluid, the properties of propping agent, displacement, the quality of sand and sand ratios, etc [18] [19] [20]. In the study area, the coal reservoirs parameters were steady and inflexible. Thus, the main principle and purpose of fracturing construction was to build a reasonable project to improve the fracture conductivity on the basis of stratigraphic conditions.

1) The influence of displacement to fracturing construction

The displacement of fracturing construction in CBM wells influence the sand carrying and geometrical morphology of fracturing fractures. Increasing the displacement would increase the fissure net pressure, therefore the geometrical morphology changes of fractures, especially the height of the fracture. Thus, it was possible to limit the fractures in fracturing layer if the displacement was controlled in a rational range.

Since 6 of those CBM wells was shut off before the stage of stable production, the average daily gas production and the average daily gas production in steady stage of the rest 18 CBM wells were statistically analyzed in this study. The result showed that the displacement was between 8 and 8.5 m³/min for those wells with high average daily gas production values (Figure 1). Moreover, the values almost had no changes if the displacement was decreased to 5 - 8 m³/min.

2) The influence of fracturing scale to fracturing construction

The fractures were the main channels of drainage and gas migration. Enlarging the fracturing scale meant the increased substance was brought into the coal seam, which would intensify spatial extension of fractures in length, width and height, especially in length direction. Generally, the fracturing effect was in proportion to fracturing scale. However, if the fracturing scale was too large, the fractures would extend to roof and floor of coal seam and link to the aquifer, which was negative for drainage and gas production. Moreover, the excessive

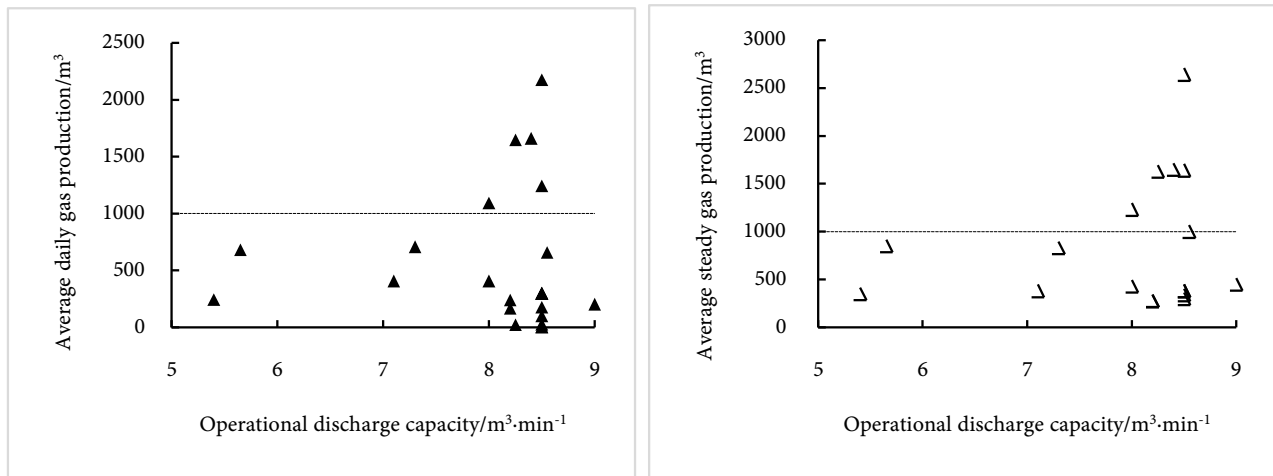


Figure 1. The relationship between operational discharge capacity and average daily and steady gas production.

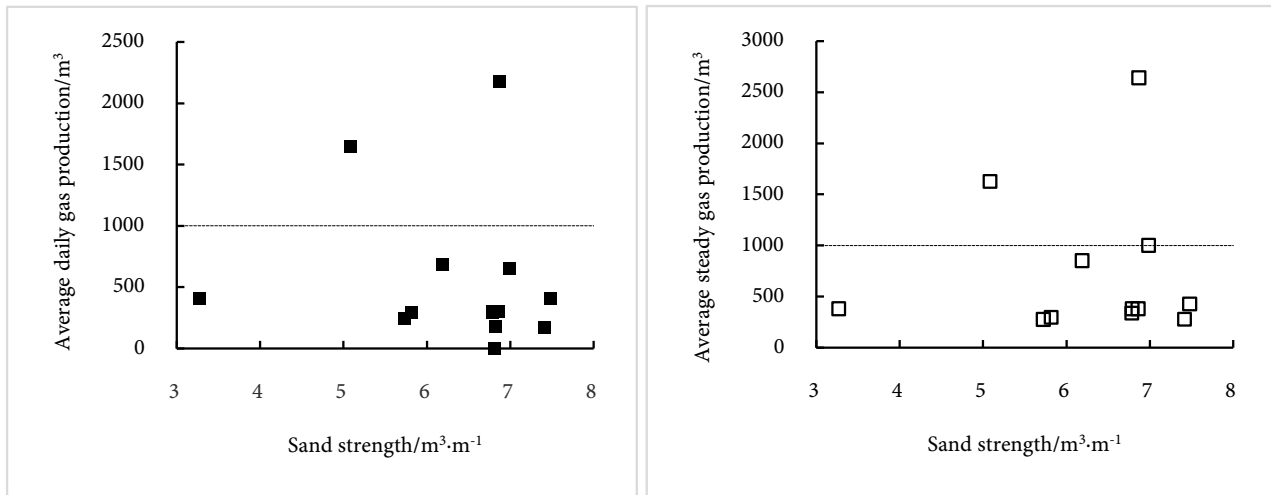
fracturing scale would destroy the coal seam structure and decrease the permeability of coal seam. Thus, the total volume of fracturing fluid and the quality of sand were critical for fracturing construction.

In the early fracturing stage, the quality of sand was relevant to the coal seam thickness. In this study, 12 m was taken as the critical thickness to discuss the relationship of the quality of sand and the gas production. The statistical relationship of the quality of sand VS the average daily gas production or the average daily gas production in steady stage, and the total volume of fracturing fluid VS the average daily gas production or the average daily gas production in steady stage were shown in **Figure 2** and **Figure 3** respectively. The result showed that: when the coal seam was thicker than 12 m, the quality of sand in CBM wells with higher production was 5 - 7 m³/m. While, in coal seam with the thickness less than 12 m, the quality of sand in CBM wells with higher production was 8 - 9 CBM m³/m. The total volume of fracturing fluid in CBM wells with high was 950 - 1100 m³, except for the BCD-133 which was high production but with the total volume of fracturing fluid 1200 m³. In other wells, the quality of sand and the total volume of fracturing fluid showed scarcely influence in gas production.

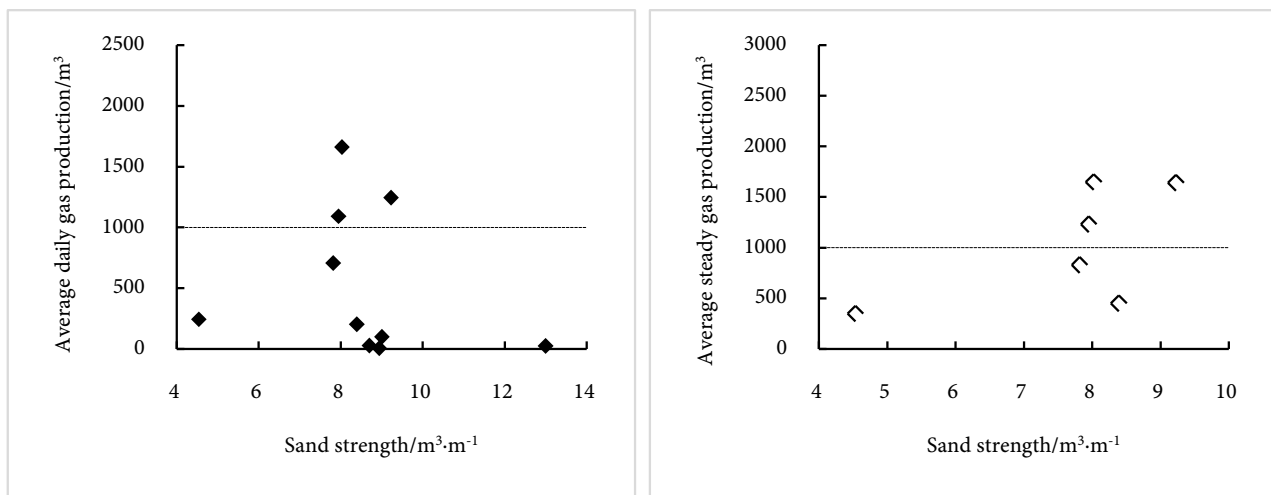
3) The influence of sand ratio to fracturing construction

There was a positive correlation between the sand ratio to the concentration of propping agent in fractures and the fracture conductivity. Since the Young's modulus of the coal seam was low, in practice, the embedded propping agent would decrease the fracture width. Thus, increasing the sand ratio would harmful to the migration of carrying fluid. Even worse, the propping agent might plug and form a sand dune in fractures which would seriously influence the fracturing construction. Thus, the sand ratio and the choice of propping agent should be considered comprehensively.

The correlations of sand ratio, the ratio of used medium sand propping agent/coarse sand propping agent and the average daily gas production, the



(a)



(b)

Figure 2. The relationship between sand strength and average daily and steady gas production. (a) The thickness of coal seam is more than or equal to 12 m; (b) The thickness of coal seam is less than 12 m.

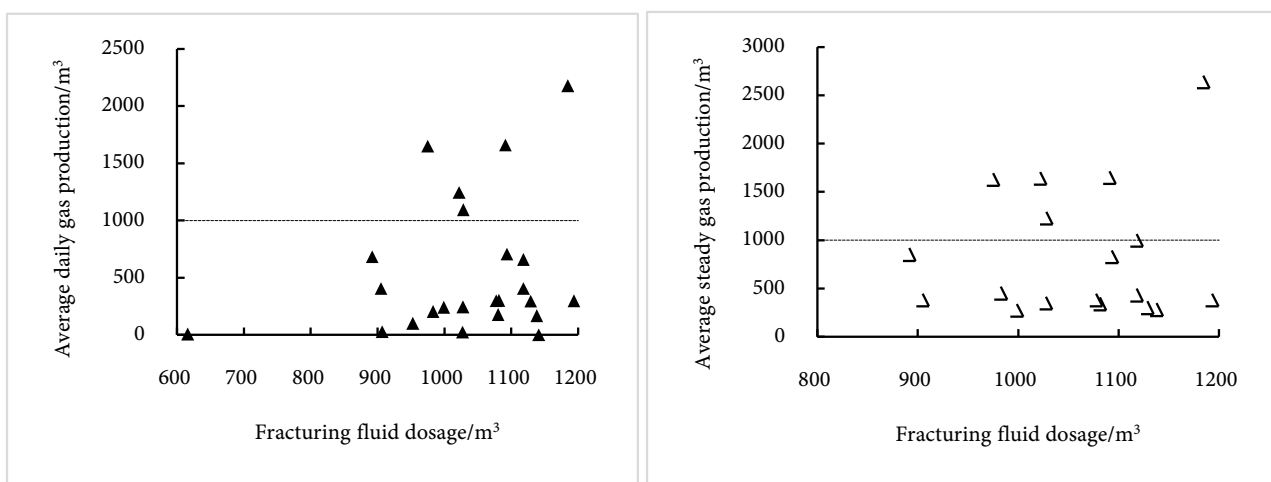


Figure 3. The relationship between fracturing fluid dosage and average daily and steady gas production.

average daily gas production in steady stage were presented in **Figure 4** and **Figure 5** respectively. As shown in the figures, in CBM wells with high production, the sand ratio was about 10% - 11%, and the ratio of used medium sand propping agent/coarse sand propping agent was between 2 and 3. In other wells, the sand ratio and the ratio of the used medium sand propping agent/coarse sand propping agent showed scarcely influence in gas production except BCD-C01, which showed high production when the sand ratio was 17%.

4.2. Optimization of Fracturing Parameters of CBM Wells

Based on the relationship between the fracturing parameters and their influence on fracturing construction, an optimization design of fracturing parameters of CBM vertical wells in Dafosi mine field was proposed as following:

1) Fracturing fluid and propping agent

Clay minerals were widely distributed in Dafosi mine field. It was important to consider the damage of coal reservoirs brought by the expansion of clay minerals with the invasion of fracturing fluid during fracturing construction. The addition of KCl in fracturing fluid could not only prevent the expansion of clay minerals, but also increase the contact angle of coalbed and fracturing fluid. It was beneficial for the drainage of fracturing fluid. Moreover, the addition of KCl showed universal and positive effect to different coal rank reservoirs. Balance the costs and effects, the active water with 1% KCl and 0.05% fungicide was suggested as the fracturing fluid.

In Dafosi mine field, the closure pressure of coalbed was low, and so was the loading strength of propping agent. From the points of reducing costs and convenient for the transportation of fracturing fluid, the economical quartz sand was suggested as the propping agent, since its strength could meet the requirements of fracturing construction.

2) Displacement

Based on former statistics, the displacement of high average daily gas production CBM wells in the Dafosi mine field was among 8 to 9 m³/min. In the real

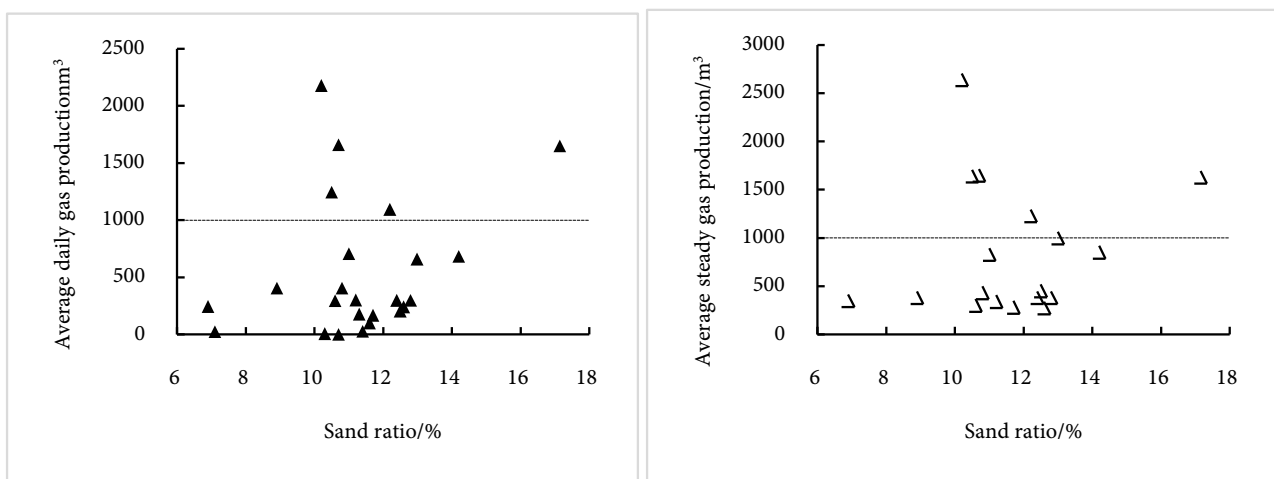


Figure 4. The relationship between sand ratio and average daily and steady gas production.

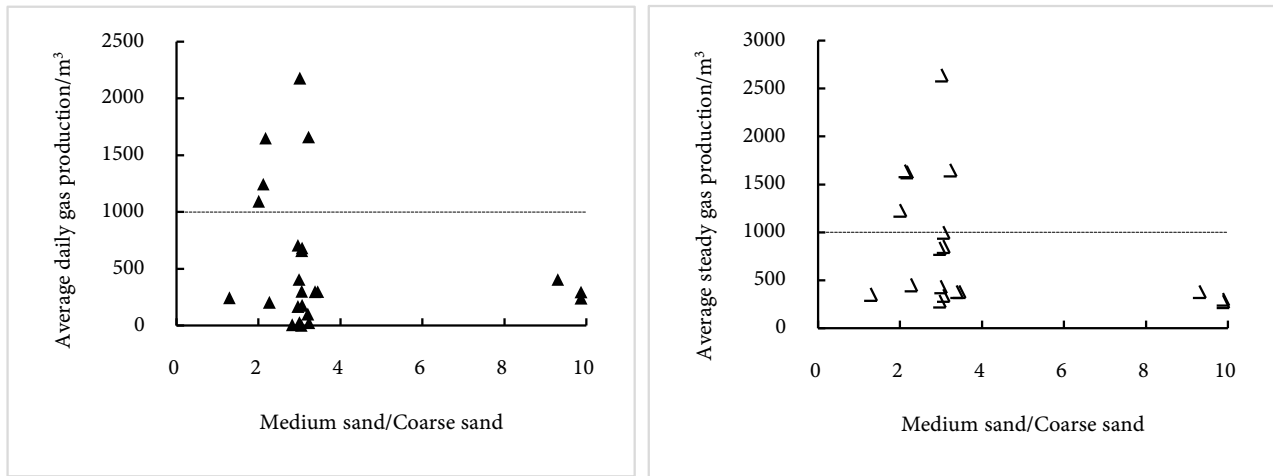


Figure 5. The relationship between medium sand/coarse sand and average daily and steady gas production.

construction process, the sand plugging occurred frequently. To improve the efficiency and fracturing effect, the displacement was set at 8 - 10 m³/min. In the study area, the coal seam was characterized by high permeability, induced great loss in fracturing field. Therefore, 1 - 2 fine sand plugs were added during preflush stage to reduce the loss and improve the efficiency of fracturing and sand carrying.

3) The total volume of fluid

The total volume of fluid included the volume of preflush fluid, the sand carrying fluid and displacement fluid. According to the construction data and the fracturing results, the construction effect was better when the displacement was between 950 and 1100 m³. Generally, the volume of preflush fluid accounted for 25% - 40% of the total volume of fluid. The volume of sand carrying fluid was determined by the quality of sand and the sand ratio. The displacement fluid was used to squash the residual sand carrying fluid in the wellbore into the stratum fractures. The volume of the displacement fluid could be calculated from the structure of the inlet pipe of the wellbore. In this study, the value was 6 - 7 m³.

4) The quality of sand and sand ratio

Based on the analyzed fracturing construction data above and considering the thickness and high permeability in No.4 coalbed in Dafosi mine field, the quality of sand was designed as following. If the coalbed was thicker than 12 m, the quality of sand was set 5 - 7 m³/m; otherwise, the value was set 8 - 9 m³/m. The coal seam was thicker in Dafosi mine field and was difficult to fracturing. In this study, the sand ratio was suggested between 10% - 11%, and the medium/coarse sand ratio in propping agents was set at 2 - 3.

5. Conclusions and Suggestion

1) In the 24 vertical CBM wells that performed fracturing construction in Dafosi mine field, most of them are increasing in production, and part of them showed good potential.

2) The main fracturing parameters that influenced the gas production of CBM wells in Dafosi mine wells included displacement, the total volume of fracturing fluid, the quality of sand, sand ratio and the volume of propping agent.

3) Based on statistical analysis of fracturing construction parameters, an optimization design of fracturing parameters was proposed as follows: the displacement was suggested to be 8 - 10 m³/min; 1 or 2 fine sand plugs were added in preflush stage; the total volume of fracturing fluid was set between 950 and 1100 m³ (with 25% - 40% preflush fluid); the quality of sand was suggested to be 5 - 7 m³/m when coal seam thickness exceeds 12 m or 8 - 9 m³/m when coal seam thickness was less than 12 m; the medium/coarse sand ratio in propping agents was set 2 - 3.

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