Improving the Technology of Hydraulic Impact Based on Accounting Previously Treated Wells

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Abstract. Based on accounting the additional stresses evolving from the previously treated wells of preliminary degassing, there is proposed a technological scheme of hydraulic impact aimed at providing hydraulic linkages between wells.

1. Introduction

The problem of extracting methane from unrelieved coal seams is more than 100 years old. So, in 1913 the use of hydraulic fracturing was proposed in the USA [1, 2]. The information of the first industrial tests belongs to the end of the twenties of the last century, however those works were carried out in the mining units where under the coal seams there lay oil and gas [3, 4] that complicated identifying unambiguously the object of the impact.

System studies of the issues of extracting methane from unrelieved coal seams were begun in our country more than 50 years ago. The first wells were processed in the Karaganda basin in 1961. Originally the works were carried out for decreasing the gas content of coal seams and the gas content of the workings. After 1973 decreasing the outburst danger [5, 6] became one of the major trends. The basic impact is hydraulic fracturing of coal seams proposed by professor N.V. Nozhkin [7, 8] whose technology was in a lot of respects borrowed from the oil branch [9, 10]. Now this technology is used in V.I. Lenin and Kazakhstanskaya mines of the Karaganda basin in vent preparation of the especially outburst dangerous δₖ seam. In the absence of protective seams there are no alternatives to this technology, but expediency of its use in a lot of respects is defined by the planned loads of the breakage face [11].

It should be noted that within a lot of years between specialists of oil-and-gas and coal branches there was a discussion regarding the terminological definition of the basic impact: hydraulic fracturing or hydraulic partition. This divergence is of great importance since it is connected with physical processes and technological solutions when carrying out an impact on a coal seam. In the first case we speak of forming new cracks, in the second case we mean disclosure of the system of cracks which are available in the seam. The technology of extracting coal methane which was widely adopted thanks to the USA companies is based on hydraulic fracturing and allocating the most prospective units of coal fields from the point of view of gas emission. It is also reflected in forming the criteria for allocating such units and in the technology of the impact.

The reason of this distinction is the purpose of carrying out such works. In the first case we speak of extracting methane and, as a result, the need of ensuring its profitability. Therefore one of the main criteria is permeability of coal seams. In the second case the purpose is safety of carrying out mining operations that imposes certain restrictions for the technology and requirements to the results of the
use, such as a minimum impact on the roof and soil rocks, degassing the entire required area irrespective of natural permeability of coal seams and some others. For achieving the uniform degassing it is necessary to provide disclosure of cracks on the entire area. The mechanism of cracks developing in the block-cracky massif was considered in a lot of works. In the conditions of coal seams with their preliminary degassing the cracks mutual impact is estimated in work [12]. The experience of treating wells of preliminary degassing in the Sokurskaya, V.I. Lenin and Karagandaskaya mines of the Karaganda basin has shown that at a significant amount of linkages with workings and raw wells there were practically no linkages with the previously treated wells that permits to assume the presence of the additional stresses interfering cracks disclosure in this direction.

For increasing the efficiency of preliminary degassing of coal seams due to the use of hydraulic linkages effect it is necessary to consider the additional stresses arising in a seam from the previously treated wells and interfering cracks development.

The used calculation model considers the impact of the following factors:
- variable modularity of the rock massif in the zone of hydrotreating and in the surrounding or enclosing zone;
- decreasing the module of the seam deformation in the hydrotreating zone when moistening coal;
- coal swelling in the hydrotreating zone;
- hydrostatic pressure in the hydrotreating zone;
- actual geometry of the zone of hydrotreating.

There have been accepted the following basic data for calculations (numerical estimates):
- the depth of coal seam $H=600$ m;
- the volume weight of the cover rocks $\gamma=2.5$ t/m$^3$;
- in the assessment of the first factor effect the ratio of the module of the coal seam deformation to the module of the enclosing rock massif deformation (extremely maximum ratio) $E_i/E=0.1$, the Poisson coefficient of the enclosing rock massif $\mu_i=0.3$, coal seam $\mu_i=0.1$;
- in the assessment of the second factor effect the module of the coal seam deformation $E_i=0.3\cdot10^4$ MPa and its decreasing when moistened to $0.8E_i$;
- in the assessment of the third factor effect the coal linear swelling $\varepsilon_0^c=0.006$;
- in the assessment of the fourth factor effect the height of the water column $H=600$ m and its volume weight $\gamma_w=1$ t/m$^3$;
- in the assessment of the fifth factor effect the diameter of the hydrotreating area in the plan $D=250$ m and the coal seam thickness $h=6$ m.

The calculations have been executed proceeding from the elastic stage of deformation of the rock massif.

The calculations have been executed separately for each of the listed factors, and there has been obtained the total score of additional stresses. The calculation expressions obtained in such a way permit to propose parameters of the technology of hydrotreating aimed at providing a linkage of the neighboring wells.

In the first approximation we will consider the zone of hydrotreating a coal seam in the form of a spherical area with the $R$ radius, the module of deformation $E_\gamma$ before treating and $0.8E_\gamma$ after treating, and with the Poisson coefficient $\mu_i$ which center of gravity is located at the $H$ depth. The rest (enclosing) rock massif has the module of deformation $E$, the Poisson coefficient $\mu$, the volume weight $\gamma$ and a hydrostatic (equal component) field of initial stresses. Such idealization of the area geometry of hydrotreating permits to find out a quality picture of the additional stress.

As the unknown value we will consider normal radial stress $P$ on the contact of the zone of hydrotreating and the enclosing massif. Then the components of stresses in the zone of hydrotreating obtained from the solution of the polar-symmetric problem are equal:

$$\sigma_\theta = \sigma_\phi = \sigma_r = P$$ (1)
Linear tangential deformations are determined from the physical equations of the theory of elasticity:

\[ \varepsilon_\theta = \varepsilon_\phi = \frac{1}{E_1} \left[ \sigma_\theta - \mu_1 \sigma_\phi + \sigma_r \right] = \frac{1}{E_1} P \left( 1 - 2 \mu_1 \right) \]

(2)

and radial displacements on the border of the contact are found from the geometrical equations:

\[ l = R \varepsilon_\theta = \frac{R}{E_1} P \left( 1 - 2 \mu_1 \right) \]

(3)

On the other hand, considering the enclosing rock massif with the spherical cavity \( R \) and the contact pressure \( P \) on its surface, we define from the solution of the polar-symmetric problem the stress component:

\[ \sigma_\theta = \sigma_\phi = \frac{3}{2} \gamma H - \frac{1}{2} P, \quad \sigma_r = P \]

(4)

tangential deformations

\[ \varepsilon_\theta = \varepsilon_\phi = \frac{1}{E} \left\{ \left( \frac{3}{2} \gamma H - \frac{1}{2} P \right) \left( 1 - \mu - \mu P \right) \right\} \]

(5)

and radial displacements

\[ l = \frac{R}{E} \left\{ \left( \frac{3}{2} \gamma H - \frac{1}{2} P \right) \left( 1 - \mu - \mu P \right) \right\} \]

(6)

Proceeding from the condition of deformation continuity on the border of the contact we equal radial displacements (3) and (6). As a result there is obtained the equation

\[ \frac{P \left( 1 - 2 \mu_1 \right)}{E_1} = \frac{1}{E} \left\{ \left( \frac{3}{2} \gamma H - \frac{1}{2} P \right) \left( 1 - \mu - \mu P \right) \right\} \]

(7)

after solving which we find the unknown contact pressure

\[ P = \frac{E_1 \frac{3}{2} \gamma H \left( 1 - \mu \right)}{1 - 2 \mu_1 + \frac{E_1}{E} \frac{1}{2} \left( 1 + \mu \right)} \]

(8)

on the border of the “rigid” enclosing massif and the “pliable” zone of hydrotreating.

Let us generalize the expression for the case of reducing the module of deformation of the moistened coal to the \( 0.8 E_1 \) level. As a result we will obtain:

\[ P = \frac{0.8 E_1 \frac{3}{2} \gamma H \left( 1 - \mu \right)}{1 - 2 \mu_1 + 0.8 \frac{E_1}{E} \frac{1}{2} \left( 1 + \mu \right)} \]

(9)

After substituting (9) in the first formula (4) we will construct the assessment of the additional stress value \( \sigma_\theta \) on the border of the zone of hydrotreating considering the effect of the variable modularity of the zone of hydrotreating and the enclosing massif, as well as the effect of decreasing the module of coal deformation by 20% when moistened:
\[
\sigma_\theta = \left( \frac{3}{2} - \frac{0.8 \frac{E_1}{E} \frac{3}{4} \frac{1-\mu}{1+\mu}}{1-2\mu_i + 0.8 \frac{E_1}{E} \frac{1}{2} \frac{1+\mu}{1-\mu}} \right) \gamma H
\] (10)

As the numerical analysis shows, the listed factors effect depends on the value of the Poisson coefficient \(\mu_i\): for the incompressible massif \((\mu_i=0.5)\) there is no this effect; for the coal massif broken by the system of cracks \((\mu_i=0)\) it reaches the maximum value:

\[
\sigma_\theta = \left( \frac{3}{2} - \frac{0.8 \frac{E_1}{E} \frac{3}{4} \frac{1-\mu}{1+\mu}}{1+0.8 \frac{E_1}{E} \frac{1}{2} \frac{1+\mu}{1-\mu}} \right) \gamma H
\] (11)

Using the last expression (11), we will estimate separately the maximum effect from the variable modularity \(E_1/E=0.1\) and from the additional decrease in the module of deformation of the moistened coal by 20%. In the first case we will obtain \(\sigma_\theta = 1.45\gamma H\), in the second case we will obtain \(\sigma_\theta = 1.46\gamma H\) that demonstrates but insignificant impact on the value of the additional stress of decreasing the module of deformation of the moistened coal and a significant effect of the variable modularity: it increases by 45%. In case of the simultaneous effect of both factors basic pressure increases by 46% that should be considered as the maximum limit assessment.

The assessment of the rest factors shows that coal swelling in the zone of hydrotreating leads to an insignificant decrease in the additional stress, and hydrostatic pressure in the zone of hydrotreating provides the 30% excess over the initial field of stresses.

The spherical zone of hydrotreating considered above is idealization and the first approach in the solution of the objective. The actual zone of hydrotreating represents an ellipsoid of rotation of a relatively small axis which makes \(h=6\) m and corresponds to the thickness of the treated coal seam. The large axis of this zone is equal according to the data to \(D=250\) m. At such a ratio of the dimensions on the zone borders within the coal seam there should be expected a higher concentration of the additional stress \(\sigma_\theta\) than it was accepted above.

In order to estimate the specified additional concentration of \(\sigma_\theta\) stresses we will consider in the deformation a working with a circular cross section where the concentration is \(\sigma_\theta = 2\gamma H\), and a working with the elliptic cross section where the concentration of stresses at the level of the large axis of the ellipse makes

\[
\sigma_\theta = 2\gamma H \frac{1+\alpha}{1-\alpha}, \text{ or } \sigma_\theta = 2\gamma H \cdot K
\] (12)

where \(\alpha\) is expressed through the ratio of the ellipse axes in such a way:

\[
\alpha = \frac{D-h}{D+h}
\] (13)

Substituting the basic data in (13), we will obtain \(\alpha=0.95\) from where by formula (12) we find the coefficient of the additional concentration of stresses in relation to the circular cross section \(K=39\) by which it is necessary to increase a certain additional stress \(\sigma_\theta\) on the borders of the spherical zone of hydrotreating.

It should be noted that actually because of nonlinearity of the coal deformation in the zone of high stresses, such a coefficient of concentration of stresses is not usually observed. Nevertheless at the set
geometrical dimensions of the zone of hydrotreating in its regional parts there can be the $K$ coefficient within $10$.

Summarizing the assessments given above on various factors, we will obtain the following calculation expression:

$$\sigma_{\theta} = \left\{ \frac{3}{2} - \frac{0.8 \frac{E_i}{E} \frac{1}{4} 1 - \mu + \frac{E_i}{E} \frac{1}{2} H}{1 - 2\mu + 0.8 \frac{E_i}{E} \frac{1}{2} 1 + \mu} \right\} \frac{1}{2} \gamma H \cdot K$$  \hspace{1cm} (14)

The quantitative assessment of additional stresses for the basic data: $E/E=0.1$; $\mu=0.3$; $\mu_i=0$; $E=0.3 \cdot 10^4$ MPa; $\gamma=0.006$; $\gamma=2.5$ t/m$^3$; $H=600$ m; $\gamma=1$ t/m$^3$; $K=10$ showed that $\sigma_{\theta} = 1.5 - 0.61 - 0.2 \cdot 10^{0.9} H = 6.9 \gamma H$.

Thus, the coal seam swelling and hydrostatic pressure of the water reduce additional stresses, but at the same time the geometry of the zone of hydrotreating provides a high coefficient of concentration of stresses in the regional parts of this zone that finally leads to a significant increase in additional stresses which, obviously, interferes with the development of cracks from the neighboring zones.

We carry out this assessment proceeding from the assumption that the treated unit is considered to be a zone of additional stresses, with pressure on the border that is equal to partition pressure, limited in space by the soil and the roof of the seam and the effective radius of effect. It is of interest both from the point of view of the mutual effect of the seams when processing the suite, and the neighboring wells.

For the second case stress distribution in the unlimited space in which there acts a concentrated load is described by the expression:

$$\sigma_z = \frac{3F}{4\pi} \frac{z^3}{R^5}.$$  \hspace{1cm} (15)

In the assessment of the effect of the previously treated well on the neighboring units of the seam in the conditions of the plane problem, the value of the additional squeezing stress (Fig. 1) out of the treating zone in the first approximation will make

$$\sigma_{\theta} = P_{\nu} \left( \frac{R}{r} \right)^2,$$  \hspace{1cm} (16)

and the value of the pulling stress is

$$\sigma_{\theta} = \theta \sigma_{\theta},$$  \hspace{1cm} (17)

where $\theta$ is the coefficient depending on the source type, in the conditions of the plane problem $\theta=1$, of the spherical one $\theta=0.5$. In our case the $\theta$ value makes approximately 0.7-0.8. Thus, with the source pressure of 7-9 MPa the value of the additional squeezing stress at the distance of 200-250 m will make from 1.2 to 1.8 MPa. The most prospective direction of the cracks development is the direction from a new well to the previously treated unit and opposite to this. Considering the effect of the additional stress in the zone adjacent to the previously treated well which dimensions can reach 20-30 m, the prevailing direction there can be the second direction. In the orthogonal direction the development of cracks will be complicated by the corresponding size. It needs to be considered when drawing up the program of the unit treating.

2. Conclusion
On the basis of analyzing the conditions of forming hydraulic linkages and taking into account a more effective development of the zone of the well located to the seam rise, there is proposed a technological scheme of cyclic well treatment providing the maximum development of cracks of fracturing to the seam rise and increasing the efficiency of treating due to the use of the effect of coal swelling. It should be considered that parallel to coal swelling which intensity depends generally on the working liquid composition [13] there takes place moistening of the enclosing rocks therefore the duration of a technological break between the cycles is an optimized size and shouldn't exceed the duration of intensive swelling.

As an example we will consider the sequence of treating two wells located to the seam dip. At the first stage there is treated the well with a larger depth of the coal seam and partial release of the working liquid pressure that provides an additional stress in the neighborhood of the zone of treating and the prevailing development of cracks when treating the neighbor well towards the seam rise. After treating the second well there is made additional treatment of the first one with the maximum speed of pumping the working liquid providing disclosure of additional systems of cracks and a possibility of forming a hydraulic linkage with the neighboring well. The duration of the technological break between the operation cycles of the first well is defined by the dynamics of coal swelling at interaction with the working liquid used.

Approximate parameters and the sequence of treating are presented in the Table 1.

| Cycle number | Well number | Depth, m | Treatment parameters | Notes |
|--------------|-------------|----------|----------------------|-------|
|              | 1           | 520      | 0.6-0.7V             | q     |
| 2            | 2           | 500      | V                    | q     |
| 3            | 1           | 520      | 0.3-0.4V             | 90-100|

It should be noted that providing linkages between the wells permits to solve the problem of increasing the efficiency of the impact on the peripheral units of the coal seam due to the simultaneous treatment of the coal seam through two wells. This problem is especially topical in the degassing preparation of the coal seams dangerous for sudden outbursts.

3. References

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