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Translation

"On the Exploitation of Oil and Gas Deposits in Low Permeability Reservoirs"

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In the course of several years, the attention of specialists [1,2] has been attracted to a new method of stimulating reservoirs--powerful explosions which experiment indicates will permit the achievement of high success in the opening up of the low permeability reservoirs. The zone of fractures created by the explosion surrounding the stimulation hole in which the explosion was carried out are able to reach out to significant distances. The effective radius of such holes is as large as several tens of meters, i.e. it exceeds the radius of a usual hole by over 100 times.

In the paper the possibility of effectively utilizing powerful explosions for exploitation of low permeability oil and gas deposits is described as well as an analysis of several experiments involving its utilization.

As is well known, an explosion forms a column of broken rock - a chimney (Figure 1)--filled with rock which has a radius of 10-20 m (depending on the yield and depth of the explosions and the properties of the rock), and its height H_c is equal to 4-5 times the radius, r_p. The permeability of the rubblized rock inside the chimney is very high - several orders of magnitudes greater than the preexisting permeability of the reservoir. Thus the effective radius of the stimulation well is able to take on the value r_p. However, in practice the effective radius of such a hole, r_e, is much larger as a result of the creation of fractures in the wall of the chimney.

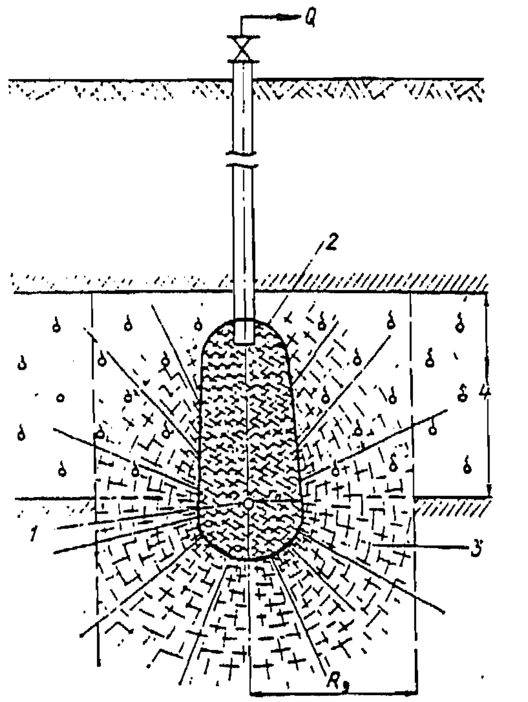

Figure 1: General diagram of the mechanical action of an explosion on the surrounding rock. 1. Center of the explosion; 2. column of rubble (chimney); 3. fracture zone; 4. gas-bearing layers.

The value of r_e is able to be defined by the formula

$$r_e = r_f e^{-\alpha} \qquad (1)$$

where

$$\alpha = \varepsilon_0 \int_{r_p}^{r_f} \frac{dr}{r\varepsilon(r-r_f)}$$

where r_f = the radius of the zone of fracturing which under realistic conditions is able to extend to several hundreds of meters, r = horizontal radius, measured from the axis of the hole (chimney), ε_0 - hydroproductivity of the deposit, $\varepsilon(r-r_1)$ - measure of the hydroproductivity beyond the walls of the chimney as a function of the radius.

Thus for the case of an exponential dependence of $\varepsilon(r)$,

$$\alpha = \varepsilon_0 \left[E_i(br_f) - E_i(br_p)\right]/\varepsilon_0 e^{-br_p} ,$$

where

$$b = \frac{\ln \varepsilon_s/\varepsilon_0}{r_f - r_p}$$

and ε_s - value of the hydroproductivity at the wall of the chimney , $E_i(br_p)$, $E_i(br_f)$ - integral modeling functions. If we take as an example $\varepsilon_s/\varepsilon_o = 10$, $r_f/r_p = 10$, then $\alpha = .61$ and $r_e = 5.4\ r_p$. Thus, in this hypothetical case the value of r_e is 5 times larger than the radius of the chimney and is 500--1000 larger than the radius of the original hole ($r_s = .1$ m). The value of r_e under the conditions of the experimental explosions the results of which are described below, was equal to 40 and 80 m.

From the calculation of r_e, the production of a stimulated hole of gas, Q_{st}, is able to be estimated according to the formula

$$Q_{st} = \frac{\Delta p^2}{\alpha\ \ell n(r_k/r_e)} \qquad (2)$$

where Δp^2 - the difference of the square of the formation pressure and the wall pressure, r_k - the established effective radius of influence of the hole, $\alpha = 116\ zpT_{pl}/\pi\varepsilon_o T_{st}$, z - coefficient of super-compressability of the gas, T_{pl} - the formation temperature, K, $T_{st} = 293°$ K, p - 0.1 megapascals.

However the stimulated hole is able to realize a considerable increase in the flow of fluids not only as a result of its very large effective radius, but also as a result of the very significant opening up of the formation.

As is well known a conventional hole is characterized by the presence of "skin effect", resulting from contamination of the surficial zone in the process of drilling, which limits the attainment of opening up of the hole. The flow of gas from such a hole Q_o, is usually defined with the aid of the expression [3]

$$\Delta p^2 = \alpha Q_o \left[\ell n \frac{r_k}{r_s} + C \right] + b_o Q_o^2 \qquad (3)$$

where b_0 - the coefficient of filtrational resistence, reflecting the influence of the disruption of the linear law of filtration in the surficial zone, C - a parameter characterizing the "skin effect", as well as the degree of opening up of the hole. It is defined by the formula [3].

$$C = 2 \quad \frac{k_o}{k_1} - 1 \quad \ell n \frac{r_1}{r_s} + \frac{k_o}{k_1} \quad C_1, \tag{4}$$

where K_0, K_1 - coefficients of permeability of the formation and the surficial zone with the radius r_1, C_1 - coefficient expressing the character of opening up, typically equal to 1/0.025 n, and n – the number of perforation holes per meter of opened up thickness of the formation.

Assuming the values of Δp^2 in formulae (2) and (3) are equal, we obtain a relation useful for estimating the increase in the production of gas holes as a result of stimulation by means of an explosion:

$$\frac{Q_{st}}{Q_o} = \frac{\ell n(r_k/r_s) + 1}{\ell n(r_k/r_e)} + \frac{b_o Q_o}{\alpha \ell n(r_k/r_e)} \tag{5}$$

For calculation of Q_{st}/Q_0 from equations (4) and (5), we assume r_e = 40 m, r_k = 800 m, r_s = 0.1 m, ε_o = 0.2 dm/cp, T_{pl} = 280°K, b_o = 1.6 (megapascal – days)^2/(1000 m^3)^2, z = 0.8, k_0/k_1 = 5, r_1/r_s = 3, n = 12. The calculated value of Q_{st}/Q_0 as a function on Q_0 is shown in Figure 2. As can be seen in this figure, even for an unlined hole (C_1 = 0), the stimulation by an explosion is able to increase its production by several times; and for a lined hole the effect is even greater.

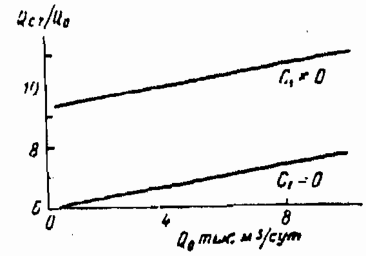

Figure 2. Graph showing dependences of the ratio of the flow from a stimulated and an ordinary well, $\frac{Q_{st}}{Q_o}$, on the normal well production, Q_0.

The example sighted above is real, taking for the calculation a low coefficient of gas productivity, a relatively high coefficient of filtrational compression b, low production rate Q_0, and a density of perferation and formation temperature as they were observed in the initial conditions of the explosions which are described below. The Zabalansovaya gas deposit, in which the explosions were carried out, is located at a depth of 1450 m and consists of a carbonate reservoir.

In the first experiment, an explosion was carried out in a hole located 120 m from an existing exploratory well which was estimated according to the results of a gas flow study to be producing 3000-5000 m^3/day. The coefficient of gas productivity of the formation was on the average 0.15 dm/cp with a permeability of 0.33 millidarcies. Before the experiment the density of perforations of the wall of the casing was increased and hydrochloric acid treatment of the production horizons were carried out but the production of gas did not increase.

Through several months after the explosion, studies were carried out in the exploratory well. It was continued for 8 months, during which period the well was in production for 75 days (producing through diaphrams of different diameters), including 35 daily test productions with a diaphram having a diameter of 11 mm. During the entire period of investigation, 7,500,000 m^3 of gas were obtained from the well. The wellhead pressure and the production ratio at the end of the testing amounted to 4.5 megapascals and 63, 000 m^3/day. In addition, simultaneously with the gas 20-22 m^3/day of oil were produced (before the explosion practically no oil appeared in the well). A year after the end of the test production the well was again entered and for a short-term produced through a diaphram of 11 mm. At this time, over the course of 5.5 days, practically the same pressure and production was observed as in the corresponding period of study a year before. This provides information about the stability of the fractures which had been formed. ?

Studies were also made in the central hole in which the explosion had been carried out. Over a period of 3.5 months of uninterrupted production testing, 11,500,000 m^3 of gas were obtained. The pressure at the mouth and the working production flow at the end of the testing period amounted to 6.9 megapascals and 50,000 m^3/day respectively. Overall the amount of gas obtained from both holes amounted to 19.6 m^3, and the calculated volume of oil produced from the exploratory well was 1200 m^3. It is of interest that the central hole, specifically the chimney, acted as an underground separator in that oil, flowing to it from the formation together with the gas, did not appear at the surface.

The second explosion was carried out in another portion of the same reservoir at a distance of 120 m from a exploratory well. However, in contrast to the other site, it did not give any significant or stabilized flow of gas before the explosion, in spite of the carrying out of dense perforation and massive hydrochoric acid treatment. The flow of gas from the well was less than 1000 m^3/day. After the explosion, experimental testing of the central hole was carried out. The pressure at the top of the hole before the beginning of the work was 10 megapascals. After two months of uninterrupted production, more than 3,500,000 m^3 of gas were obtained. The production was obtained with a well-head pressure of 7.2 megapascals and a working production of 38,000 m^3/day.

From the data cited above it is obvious that the daily flow of gas to the hole after its stimulation by the explosion in both experiments was typically an order of magnitude increased over the pre-existing production from the holes.

Experimental explosions for the stimulation of low permeability reservoirs have also occurred in the U.S.A. - the experiments "Gasbuggy", "Rulison", and "Rio Blanco". Here the reservoirs were gas containing sandstones with very low permeability, .003-.02 millidarcies. Nevertheless significant increases in the flow of gas was obtained.

Thus, in the experiment "Gasbuggy", over 310 days of production testing of the stimulated hole 11,100,000 m^3 of gas were obtained. The final production amounted to 4,530 m^3/day and exceeded the pre-existing rate (765 m^3/day) by 6 times.

In the "Rulison" experiment over 179 days of production from the stimulated hole, 12,900,000 m^3 of gas total were obtained, equivalent to a 10 year of production of gas from the pre-existing hole.

The data provided above presents a factual confirmation of the reality of the possibility of effectively using powerful explosions for the purpose of intensifying the flow of fluids and the industrial exploitation of low permeability deposits of oil and gas.

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Translation by M. Nordyke, LLNL