AGH DRILLING, OIL, GAS • Vol. 32 • No. 2 • 2015

http://dx.doi.org/10.7494/drill.2015.32.2.303

**Jan Ziaja*, Vasyl Movchan***

# COMPARATIVE ANALYSIS OF TECHNOLOGICAL EFFICIENCY OF OIL PRODUCTION INTENSIFICATION IN CARBONATE COLLECTOR. ADVANTAGES OF THE TECHNOLOGY OF RADIAL DRILLING**

## 1. INTRODUCTION

To present time, there are developed a variety of technologies for enhanced recovery of oil in carbonate reservoirs. In the oil fields of the Russia traditional methods are acid treatment (AT) and cumulative perforation (CP) of production intervals. High efficiency showed radial drilling technology (RDT) and boring perforation (BP) in conjunction with the acid treatment at the final stage of work. The principle of radial drilling technology of perforation and boring is to create a radial channels (holes) in the productive part of the section penetrated by the well: the radial drilling channels have a length of 100 m, with perforation boring – up to 2 m [1, 2]. Has been argued that technological effect after radial drilling and boring perforation is a result of the acid treatment in the final stages [3]. For comparative assessment of the technological efficiency of acid treatment, re-jet perforation, radial drilling and boring perforation, was made the analysis of geological and technical measures (GTM) for the period 2008–2013.

## 2. ANALYSIS OF THE METHODS OF INTENSIFICATION OF OIL PRODUCTION

In the oil fields of the Russia radial drilling began to apply Since 2008, over 400 GTM, boring perforation applied since 2009, over 100 GTM. Number of performed operations

* AGH University of Science and Technology, Faculty of Drilling, Oil and Gas, Krakow, Poland

** This work was created of the statutory audit in the Department of Drilling and Geoengineering, Faculty of Drilling, Oil and Gas AGH UST

of acid treatment, jet perforation, radial drilling and boring perforations for the period 2008–2013 y. are shown in Figure 1. The best technological parameters observed after radial drilling and boring perforation, oil flow rates after GTM increased on average 3.3–3.5 times, that indicate that high-quality selection of wells and efficiency of technologies. After the re-jet perforation and acidizing performance indicators are also quite high, the magnification of flow rates – about 2.9 times.

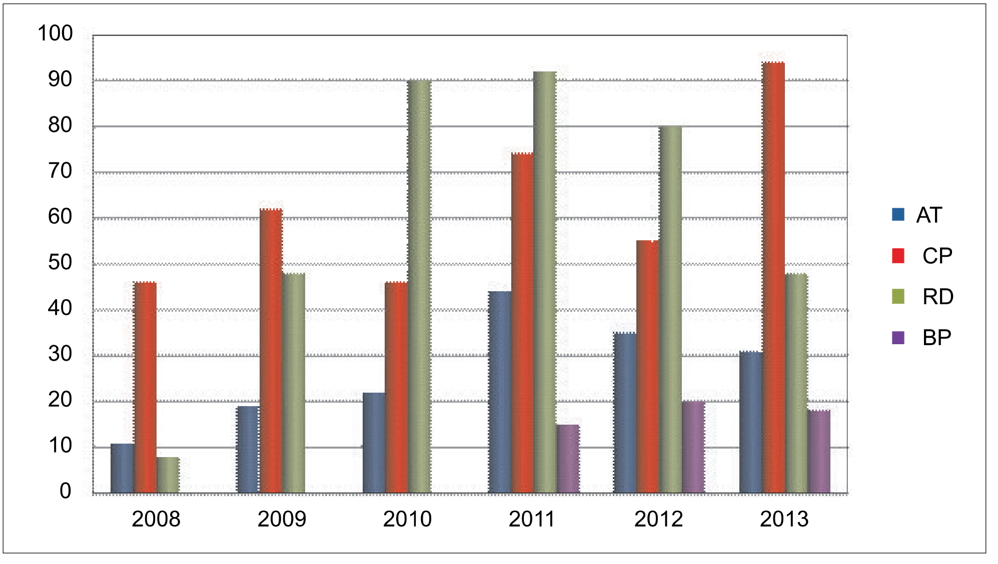


**Fig. 1.** The number performed operations of acid treatment, jet perforation, radial drilling and boring perforations in the period 2008–2013

To compare the effectiveness of the methods was discussed the results of the GTM within the same reservoir. Thus, for each technology separately estimate the average daily flow of oil through the development targets, allowing a comparison of technological efficiency between themselves. For radial drilling technology, jet perforation and acid treatments reviewed 54 facilities development, of which 26 wells premises was boring perforation.

Gain distributions technology as follows:

- the largest increase on the projects:
  - 36 facilities (67%) – radial drilling (average of 7.7 t/d);
  - 13 facilities (24%) – acid treatment and re-jet perforation (an average of 7.5 t/d);
  - 8 out of 26 facilities (31%) – perforation boring (6.4 t/d);
- gains at the secondary level:
  - 6 facilities (11%) – radial drilling (average of 6.1 t/d);
  - 8 facilities (15%) – acid treatment and reuse cumulative perforation (average 5,5 t/d);
  - 11 out of 26 facilities (42%) – boring perforations (6.2 t/d);

– the smallest increase:
  • 12 fecilities (22%) – radial drilling (average of 5.8 t/d);
  • 33 facilities (61%) – acid processing and re-cumulative perforations (average 5.2 m/d);
  • 7 out of 26 facilities (27%) – perforation boring (4.5 t/d).

Further, to eliminate the influence of individual sub-standard results was selected only those objects, where it was held three or more GTM. The average growth after radial drilling is greater than after the jet perforation and acid treatments, in 95% of cases (19 out of 20 facilities); after boring perforation (compared to BP and AT) – in 86% of cases (6 of 7 facilities).

Thus, the results of the analysis indicated an increase in increments of oil production after radial drilling and boring perforation compared with the methods of jet perforation and acid treatments on the same objects of development. This fact can be explained by the increase of the effective radius of wells, and also increase of coverage of the influence of acid composition with creating a radial canals. With acid treatments in the final stages is provided the impact to the opening by radial drilling or boring perforation along the entire length of the channel. In some cases the jet perforation insufficient to provide appropriate such interlayers the acceleration during injection of acid composition. Often acid treatment affect to other interlayers with higher acceleration, especially in the range of treatment in general. For a more visual representation the technologies of radial drilling and boring perforation were analyzed the results of the treatments in the same wells. Such treatments were held at three wells of different fields in Russia. Oil flow rates after radial drilling increased in average to 5 times, after perforation boring – to 2.8 times.

**Well A.** With the help of radial drilling was performed a second autopsy of productive interlayers on 2 levels, drilled by 2 channels at each level phasing 180$^{o}$. The total thickness of the exposed interlayer is 2.2 m. At the final stage was held the injection of acid composition with volume of 40 $m^3$ in total perforation interval. Acid treatment performer with composition in a volume of 18 $m^3$ in the general range of perforations. Boring perforation was performed at one level, were drilled 3 channels phasing of 120$^{o}$. The thickness of the exposed interlayer was 0,8 m, the interval was initially opened. Acid treatment was performer with composition in a volume of 18 $m^3$ in the general range of perforations.

**Well B.** Radial drilling carried out on 3 levels, totally were drilled 4 channels: 2 channels with 200$^{o}$ phasing at the first level and one for the second and the third levels. Acid treatment was performed with the composition in a volume of 40 $m^3$ in the general range of perforations. Boring perforation was performed at one level, were drilled 3 channels phasing of 90$^{o}$. The thickness of the exposed interlayer was 1.6 m, the interval was initially opened. Acid treatment was performer with composition in a volume of 25 $m^3$ in the general range of perforations.

**Well C.** Radial drilling carried out on 2 levels, drilled by 2 channels at each level of phasing 90$^{o}$. The total thickness of the exposed interlayer is 3.6 m. Acid treatment performer with composition in a volume of 40 $m^3$ in the general range of perforations. Boring perforation was performed at two levels, were drilled 3 channels phasing of 120$^{o}$. The thickness of the exposed interlayer was 1.4 m, the interval was initially opened. Acid treatment was performer with composition in a volume of 26 $m^3$ in the general range of perforations.

Thus, radial drilling technology and boring perforation were in wells A, B, C, a standard amount of channels were drilled considering the geological structure of the productive intervals, at the end were gotten the expected results. During the radial drilling technology was covered more interlayers, pumped large amounts of acidic compounds that provided higher growth of flow rate.

As practice shows, radial drilling is not always effective for low-powerful interlayers, there are cases when after boring perforation under similar conditions, efficiency becomes higher [4]. To identify the boundary conditions in thickness in order to support more effective technology analysis of the channels and levels depending on the thickness of the exposed interlayers.

There was drown the growth of dependence between the growth of flow rate after boring perforation ($Q_{bp}$) and growth of flow rate after radial drilling ($Q_{rd}$) from total thickness of the opened interlayers (Fig. 2).

On interlayers with thickness up to 1.8 m growth in flow rate obtained after the radial drilling compared with a gain after piercing perforations. Typical technology of opening the interlayer with thickness of 2 m implies a one-level layout of the channel, which is confirmed by many operations. In this way, for reasons of rationality holding a one-tier technology of boring perforation on interlayers with thickness less than 1.8 m has higher priority solution because of lower cost.

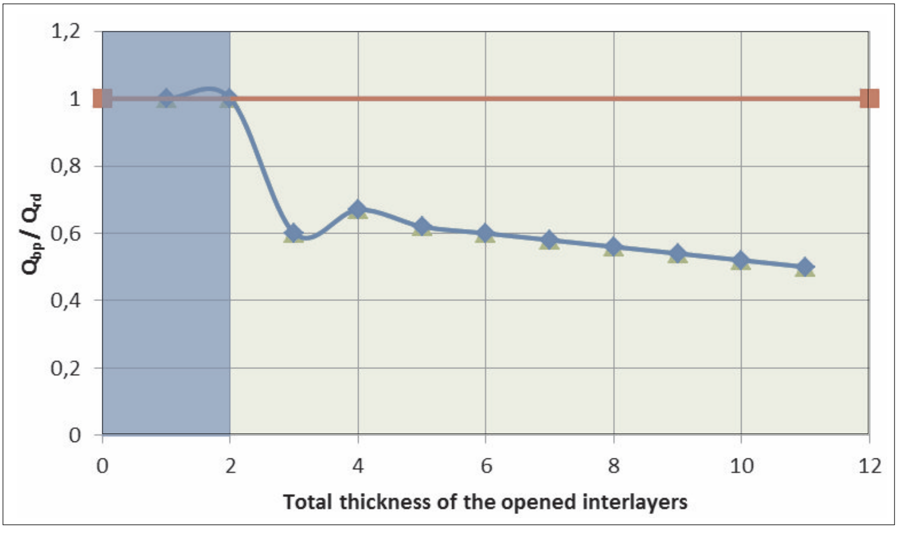


**Fig. 2.** Grath of dependence between the growth of flow rate after boring perforation ($Q_{bp}$) and growth of flow rate after radial drilling ($Q_{rd}$) from total thickness of the opened interlayers

As already mentioned, technology of radial drilling permit higher efficiency compared with traditional methods of intensification on carbonate collectors. However, the ranges of growth in flow rate at different objects are significantly different that may be due to the influence of various factors. In order to determine eligibility criteria of radial drilling technologies was conducted analysis of the efficiency of GTM from different geological and physical characteristics of the reservoir. In order to avoid of numerous factors related to geological macro inhomogeneity of objects, for analysis was selected one development object, which held the largest number of well interventions by radial drilling. Because of little experience of boring perforation it was difficult to choose the deposit with sufficient number of executed operations for the analysis.

Selected for the analysis object is dedicated to the carbonate deposits in depositstratum-arched type, the average oil-saturated thickness is about 10 m, average porosity – about 12%, the formation is characterized by high rates of sand content and fragmentation, heavy oil with high viscosity, high-sulfur with paraffin. Considered deposit allocated any abnormal properties compared to other deposits in the Perm region.

Radial drilling on the object is carried out since 2008, were held more than 40 well operations. Technology implemented in various patterns depending on the number and the total thickness of the exposed interlayers. Typical implemented modifications of the technology suggest drilling 4 side channels, a number of levels 1–4.

Energy state in different parts of the deposit is not the same, on considered wells varies in the range of 0.4–1.2 of the saturation pressure of oil gas. It should be noted that were used for analyzing only those hydrodynamic research, which were conducted on the wells before or after the GTM within one year.

It is being mentioned the growth of oil flow rates at higher reservoir pressure in excess of reservoir pressure greater than 0.55 and 0.8 of the initial saturation pressure, is observed the consistently high efficiency of the radial drilling (Fig. 3). This demonstrates the high importance of the energy criterion when technology is being planed.

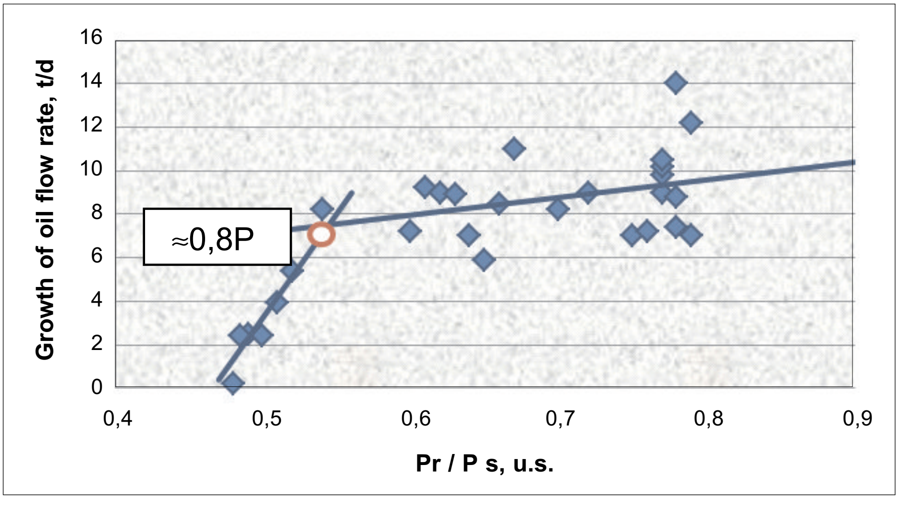


**Fig. 3.** Graph of growth in oil flow rate from the relations between the reservoir pressure and initial reservoir pressure

Reservoir permeability in these wells ranges from 0.002 to 0.05 μm$^2$. Figure 4 is a graph of dependence between growth in oil flow rate from permeability. The largest increase in oil flow rate marked on middle-permeable collectors, and when permeability is less than 0.01 μm$^2$, there is marked the effectiveness reduction of the technology.

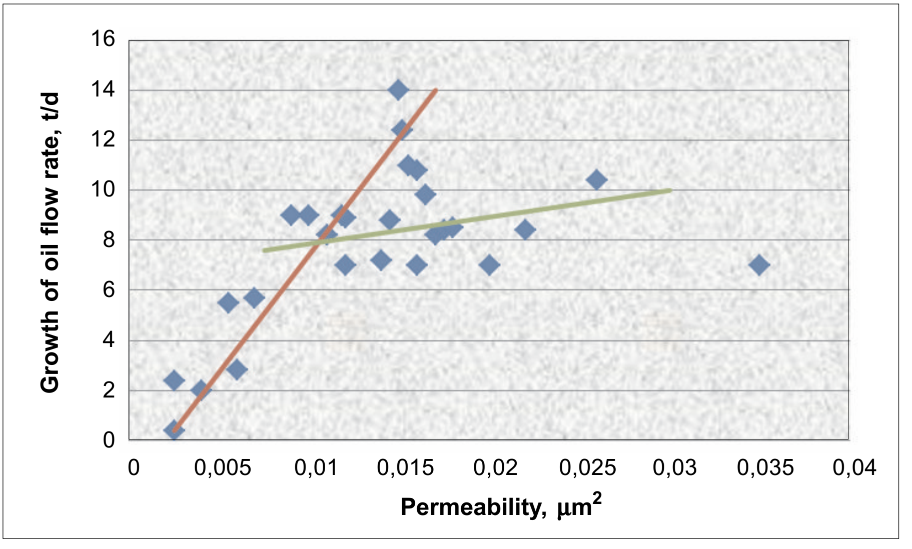


**Fig. 4.** Graph of dependence between the growth of oil flow rate and permeability

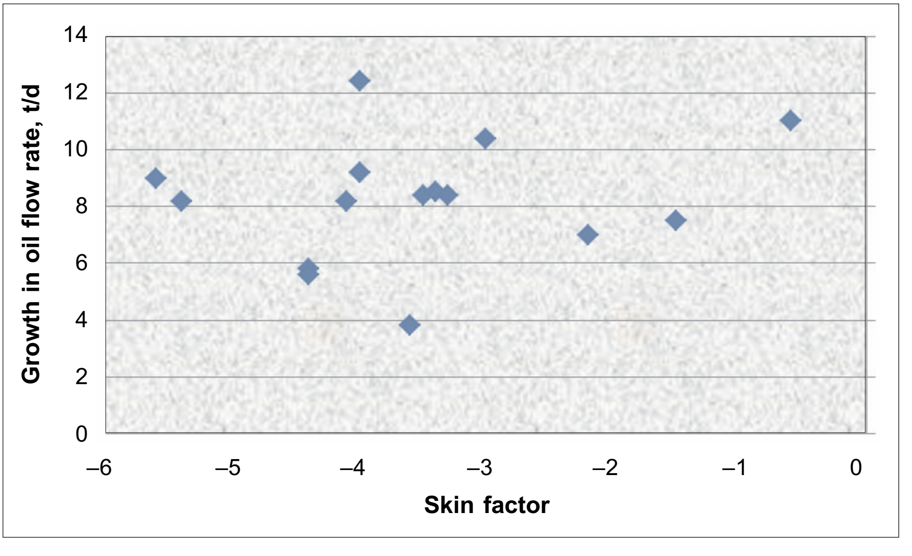


**Fig. 5.** Graph of dependence between the growth of oil flow rate and skin factor

Have been estimated the efficiency of technology depending on condition of the bottom hole formation zone. To do this, was considered the results of hydrodynamic researches on the wells, no later than a year before the GTM. Figure 5 shows the growth in oil flow rate in dependence from the skin factor. The graph shows that the apparent trends of changing in technology efficiency in dependence on the condition of bottom hole formation zone are not observed. This indicates that the technological effect of the radial drilling was achieved mainly due to the connection undrained interlayers and increasing the effective radius of the filtration around the well [7–9].

The effectiveness of radial drilling largely depends on acid treatment in the final stage. Acid treatment is carried out either "common filter" (once on all exposed perforation and radial drilling intervals), or interval standardized for each opening interlayers. During the acid treatment (without radial drilling) technological efficiency is directly related to the total thickness of the processed interlayers. To understand in some extent the effect of the acid treatment in the general range of perforation and in radial and channels may be estimated from the following considerations [10, 11].

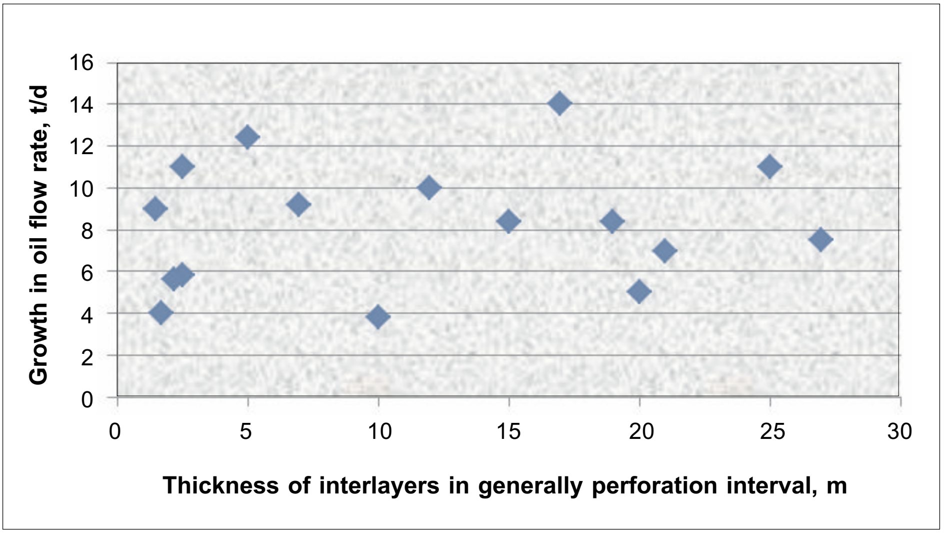


**Fig. 6.** Graph of the dependence between the growth in oil flow rate and the thickness of interlayers in generally perforation interval

For the analysis were selected wells where the pumping of acidic compositions was made in the general range of perforations (not interval standardized). Were drawn the graphs of the dependence between the growth in oil flow rate and the thickness of interlayers in generally perforation interval (Fig. 6) and from the thickness of the interlayer, exposed by radial drilling (Fig. 7).

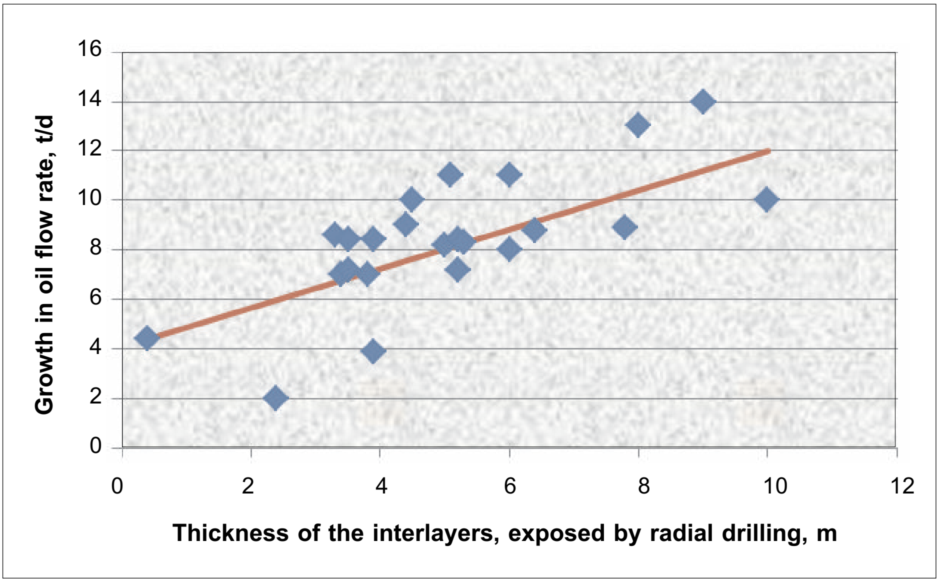


**Fig. 7.** Graph of the dependence between the growth in oil flow rate and the thickness of the interlayer, exposed by radial drilling

Thus, the technological effect of the radial drilling is more dependent on the thickness of the interlayer, exposed radial channels, rather than by dissected total thickness. In other words, technological efficiency of GTM directly depends on the thickness of the interlayer performer by radial drilling, and practically does not depend on the thickness of the remaining unperformed interlayers processed by acid compositions in the final stage of works [12].

## 3. CONCLUSIONS

According to the results of the analysis can be made the following conclusions:

1. Methods of boring perforation and radial drilling can achieve a better increasing in oil production than the acid treatment and the cumulative perforation, which is confirmed by the results of comparing the effectiveness of technology in similar geological and physical conditions. This fact confirms the effectiveness of drilling the radial channels by connecting the undrained interlayers and increasing the filtration area.
2. Recommended technology criteria for selecting the wells for radial drilling are high level of reservoir pressure, permeability of more than 0.01 $mm^2$ and less watering of production wells then 50%.

3. Boring perforation should be carried out on a total thickness of interlayers less than 1.8 m, at the opening of intervals with close proximity of water saturated interlayers, also in wells, which have certain risks in having a radial drilling due to the proximity of the lateral boundaries of the displacement front. The recommended criteria for selection the wells is a high reservoir pressure.

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