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**PRODUCTIVITY STIMULATION OF DEPLETED RESERVOIRS
BY APPLYING NEW TECHNOLOGIES
TO OPEN THE PRODUCTIVE LAYERS**

1. INTRODUCTION

The greatest natural gas fields belonging to Romgaz company are characterized by an advanced stage of exploitation, which actually involves a special approach, from the perspective of the works performed in the wells.

This aspect combined with the new geological data acquisition created the premises for developing the opportunities for capitalization of the new reserves volumes, by applying the advanced technologies of opening productive layers by reperforation and additional perforation operations with deep penetration guns, using also underbalance conditions.

**2. SOME GENERAL CONSIDERATIONS
REGARDING THE ROMGAZ STRATEGY
IN STIMULATION PRODUCTIVITY
OF THE NATURAL GAS WELLS**

One of the major objective of Romgaz strategy is represented by the increasing of the gas resources and reserves portfolio through the discovery of new resources and the improvement of the recovery rate of already discovered resources.

In this context, a special attention is given to the geological research activity, creating therefore the new opportunities for developing the greatest mature gas fields. The recently 3D seismic acquisition represents a real challenge for Romgaz specialists

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in building new geological static and dynamic models, which allowed to identify some unknown zones, less drained or even undrained zones.

From well testing for reservoir evaluation to completion and temporary workover, perforating is a key to successful gas production, long-term well productivity and efficient hydrocarbon recovery.

Selecting the most accurate intervals represents the first major step for a successful perforation job. The Romgaz old database consisting in standard electrical logs used in principal for selecting the perforation intervals, was completed in the last period with the new generation of neutronic methods with a generic name of **ABC logs (Analysis Behind Casing)** as **PNN, RST, Raptor N-Vision (CRE)** (Fig. 1), which incorporate data processing and interpretation for state-of-the-art formation evaluation and have a major application in reservoir management optimization by finding “bypassed” zones and defining the formation porosity, lithology, clay volume, fluid saturation, etc.

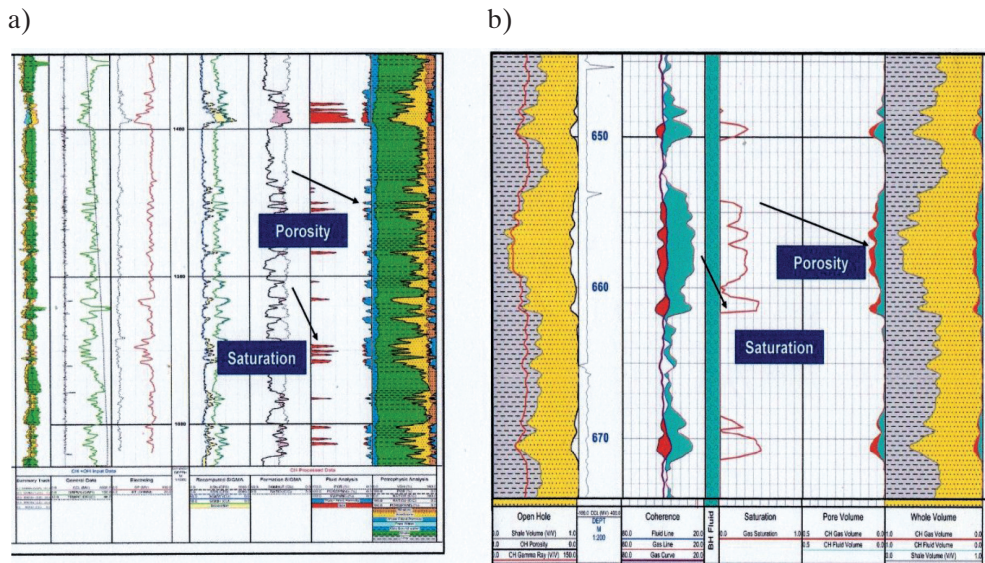


Fig. 1. Cased hole logs – PNN (a) and Raptor N-Vision CRE (b)

In case of new drilled wells, the formation tester device as RCI, is a very useful tool for selecting the future possible perforation zones, based on the reservoir parameters as permeability and downhole pressure obtained during testing.

In accordance with the continuous progress made in the world oil and gas industry, developing the new technologies regarding drilling, cementing and well completion, has also determined the changing of our concept regarding perforation jobs, which has to take into consideration a lot of factors including reservoir pressure and temperature, zone thickness and lithology, porosity, permeability, anisotropy, skin factor.

The perforation guns selection is based on the main following criteria:

- well completion,
- lithology,
- the type and parameters of drilling fluid,
- physical properties of the mechanical cores if available,
- the actual reservoir pressure (the actual pore pressure gradient),
- geological data provided by the mud logging unit.

For gun positioning in front of the desired layer, is recorded a gamma ray curve or even a neutronic one, in some special cases, which is very carefully correlated by the geologist with the existing open hole log (in principal standard electrical log) or other cased hole log if available (PNN, Cement bond log etc.). In the same run is recorded the casing collar locator (CCL), which represents also a very useful tool for correlation and for an accurate setting of the gun. This is more rigorous procedure in compare with the cable measurement used in the past.

For a proper well perforation design is very important to know the types of guns and their technical specifications (size, the hole diameter in casing, the shot density, disposal, the penetration depth, etc.).

In the past the most usually perforation guns were those with individual charge as I 43×18 shots/m and I 54×13 shots/m run through tubing, replaced now with the wire carrier gun system 1-11/16 inch and 2-1/8 inch, having the same shot density. If these guns have a penetration of only 15 and respectively 18 inch, the new wellbore conditions imposed using deep penetration guns as hollow carrier gun system 2 in DP×20 shots/m (24.40 inch), run also through tubing.

Beginning with the year 2004, a new option has been developed, being used other two deep penetration hollow carrier gun systems as 3-3/8 inch and 4 inch, especially designed for low porosity sandstones, silty rocks and thin layers of sandstones interbedded with thicker sequences of clays. These types of guns require pulling out the tubing string, are run in casing and have higher penetration, like 26.61 inch (3-3/8 DP) and 31.6 inch (4 DP).

More recently, especially for the new drilled exploration wells, with initial pore pressure gradients, in Romgaz has been implemented the Tubing Conveyed System (TCP guns), with different sizes 2-7/8 in, 3-3/8 in, and 4 in.

In parallel with development of the new concept regarding the perforation system, the strategy related to the perforation fluids has also been changed. The option to perforate the wells filled with fluid with a hydrostatic pressure higher than the formation pore pressure, has a great disadvantage, increasing the skin factor due to invasion effect, the gas flowing from reservoir into the wellbore becoming in this case more difficult.

In the context of our depleted reservoirs, with very low actual reservoir pressures, the new Romgaz concern is based on different borehole condition, consisting in creating an underbalance system, with no fluid inside the wellbore or with a very small amount

of specially designed fluids for productive layer, only to cover the gun, by using a special sealing system called BOWEN preventor.

During a workover job, in case of performing a cement plug, the underbalance conditions are realized by swabbing operation or nitrogen displacement, in order to remove the existing fluids before perforating the well.

We mention here also the recently using of the Snubbing unit for handling the tubing string without killing the wells, which represents actually the successful key for productivity stimulation in our case of depleted reservoirs.

The result of perforating in this closed system can be noticed immediately, reducing the undesired risk of fluid invasion in the formation and therefore the additional skin induced by the perforating job. In the same time the period in order to put the well in production is considerably decreased.

3. CASE STUDIES ILLUSTRATING THE STIMULATION PRODUCTIVITY BY USING THE NEW PERFORATION TECHNOLOGIES

As part of the rehabilitation project of one mature gas field located in Transylvanian Basin, a recently implemented initiative of the Romgaz management, an important remark is represented by the new challenge regarding the re-introducing in exploitation of Sarmatian VII horizon, converted into underground gas storage in the period of time 2003–2009.

The Romgaz strategy in this direction has been focused on some less drained areas or even undrained zones, revealed by the new geological model built on 3D seismic acquisitions, consisting in a new structural architecture with a complex network of faults, which separate more blocks (called “segments”) a totally different model than the previous one interpreted as an unfolded brachianticline.

The complex analysis of the integrated project team in terms of geology, geophysics and reservoir management, based on real economical reasons was completed with selecting the best well candidates which can provide the most successful results by increasing the productivity. In this context, the rehabilitation program included jobs like reperforations, additional perforations, re-entry in one abandoned well and also one deepening job.

Two relevant case studies are presented in this chapter, which demonstrate the efficiency of the new technologies in terms of perforation guns and the whole well – reservoir system, in very strict underbalance conditions, respectively with the well flowing and no fluid inside. After drifting the wells with gauges of different sizes, the proper type of guns have been selected and the perforation intervals were established based on the available logs as standard electrical and special open hole logs. Since these jobs were performed without workover rigs, by using only the snubbing unit for completion, the effective operational time has been considerable reduced.

3.1. Well A (Figs 2–4)

In case of well A, located in an undrained area, with last production from Sarmatian VIII, were reperforated and additional perforated some intervals from Sarmatian VII (an older productive layer of the well), in underbalance conditions, with 3-3/8 in DP guns × 20 shots/m and BOWEN system preventor. Pulling out the tubing string and the final completion were performed with snubbing unit.

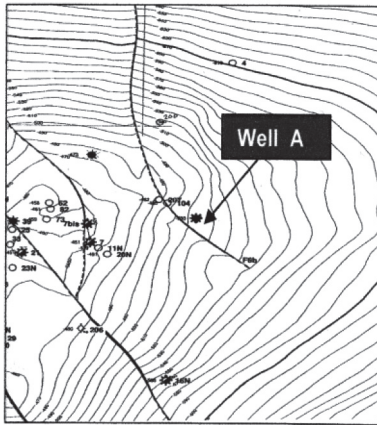


Fig. 2. Well A position

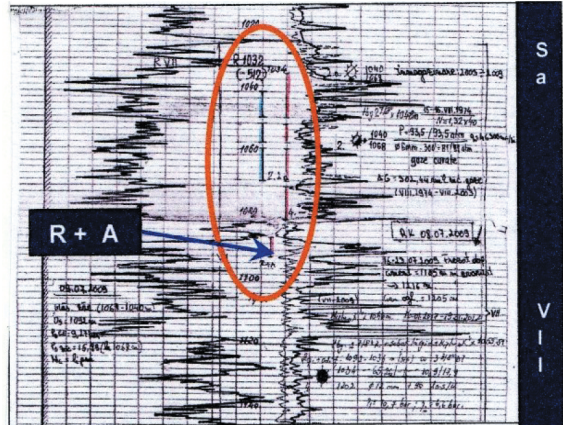


Fig. 3. Well A – standard electrical log

We mention that the average rate in Sarmatian VIII was $3000 \text{ m}^3/\text{day}$ and the result after the job was an increasing of the well flowrate to about $70.000 \text{ m}^3/\text{day}$.

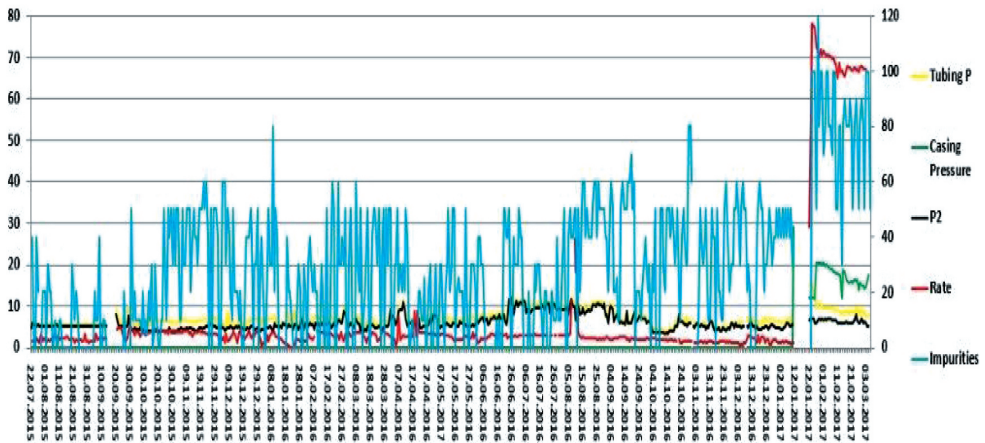


Fig. 4. Well A – behavior in exploitation before and after the perforation job

3.2. Well B (Figs 5–8)

In case of well B, a more recently drilled well, located also in an undrained area, producing before from Sarmatian VIII, was chosen the option of perforating additional layers of the new horizon (Sarmatian VII), using 3-3/8 in DP guns \times 20 shots/m and also in underbalance conditions, with BOWEN system preventer. Pulling out the tubing string and the final completion were performed with snubbing unit.

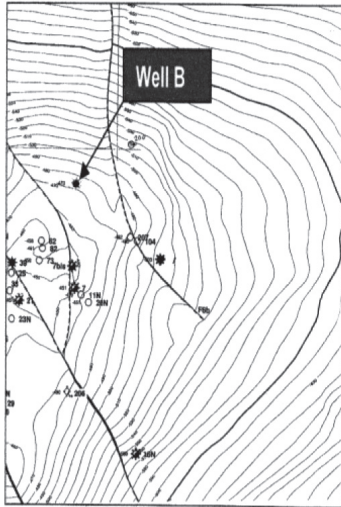


Fig. 5. Well B position

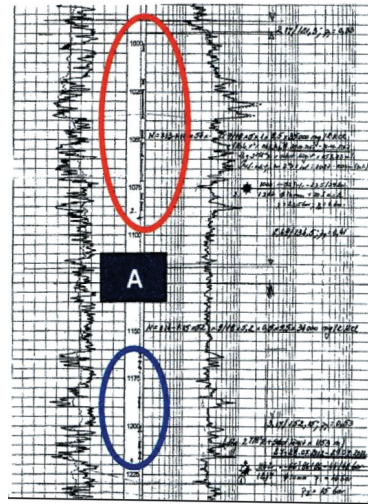


Fig. 6. Standard electrical log

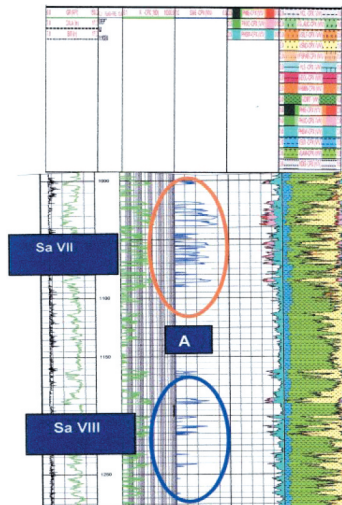


Fig. 7. Petrophysical interpretation

The perforation intervals have been selected based on petrophysical interpretation of special open hole logs, which indicated an effective porosity of 15–20% and gas saturation of 60–65%.

The average well flowrate in Sarmatian VIII was less than **25.000** m³/day and the result after the job was an increasing of the well flowrate to about **90.000** m³/day.

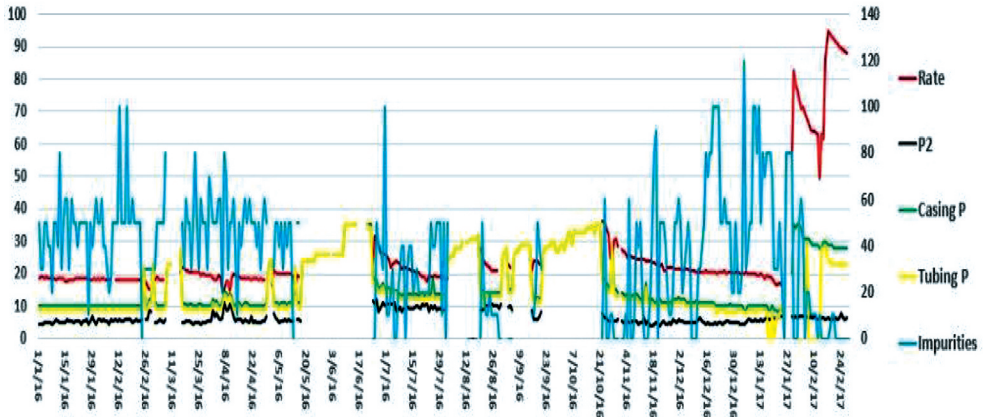


Fig. 8. Well B – behavior in exploitation before and after the perforation job

4. CONCLUSIONS

1. One of the most important concern of Romgaz strategy on reservoir management is the mature gas fields rehabilitation, a concept more frequently used in the world oil and gas industry which means in fact the extending the life of the reservoir, in terms of increasing the gas reserves and the final recovery factor.
2. The obvious decline of the natural gas reserves associated with relatively reduced volumes of the new reserves discoveries reclaim the implementation of a new philosophy and strategy of technical – economical approach of the mature gas fields rehabilitation.
3. The new geological modeling based on the recently 3D seismic acquisitions and the last generation of cased hole methods (so called ABC logs) represent a very useful tool to discover new less drained or even undrained areas and to identify by – passed layers.
4. In our specific case of depleted reservoirs, the practice has demonstrated that underbalance is essential to partially or in some cases completely remove damage and debris from perforations, reducing the undesired risk of fluid invasion in the formation and in the same time decreasing the period in order to put the well in production.

5. The smart perforating practices in terms of gun types, shaped charge, shot density, penetration, maximize the well productivity and help to realize the most efficient and effective perforating operations.

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