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THE INFLUENCE OF THE PERFORATION DENSITY AND DAMAGED ZONE PERMEABILITY ON A GAS WELL PRODUCTION

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ABSTRACT

The exploitation of wellbore condensate deposits must be carried out in such a way that both water and condensate from the productive layer are not entrained during extraction. That is precisely why the article analyzes the effect of the density of perforations of the productive layer on the amount of extracted gas. The effect of the area affected by the drilling on the produced gas flow is also studied. After 50 years since the first use of the mechanical realization of the perforations of the productive layers of the gas wells, there is little data regarding the influence of the perforation geometry of a gas well, namely the way of communication between the production layer and the borehole, on its production. The aim of this paper is to simulate the operation of the well for different values specific to the drilling mode, highlighting its production. The problem is addressed by nodal analysis. The numerical simulators were used to simulate the flow of the mixture through the layer-well system and respectively through the mixture pipe.

Keywords: nodal analysis, gas well, IPR, VLP, field pressure, flow, pipe.

INTRODUCTION

In order to maximize the production of gas since 1932, the perforation of the productive strata by shooting is used. The first perforation was made in 1932 on the Montebello structure and was made by Union Oil Co. of California [1]. Over the years, other methods have been used to penetrate the area affected by the drilling operations and to put the productive layers into production, namely fluid jet piercing or various types of shooting [2].

Although shot drilling is the most used method and gives quite good results, laboratory studies have found that rock crushing and compaction during the process of increasing the productivity of the productive layers are not taken into account, usually considering - it is known that the fluid jet in the layer passes through clean and undamaged perforations [3].

Recently [4] the efficiency of perforation on the productive layer was calculated on a set of cores extracted from the deposit, but it was not possible to analyze the effect of the condensate from the gas wells on the productivity of the productive layer and especially on the perforations of the well.

In this study it was used for the analysis of the operation of a gas well was performed using the "System Analysis" by PERFORM simulation program [5].

„System Analysis" analyzes the system by focusing on one point, or node, within the series of components and is a technique for simulating a producing well system .

As the well system is simulated, each of the components is modeled using equations or correlations to determine the pressure loss through that component as a function of flow rate [6, 7].

The summation of the individual pressure losses makes up the total pressure loss through the system for a given flow rate.

The total pressure loss is ultimately realized as the overall difference between average reservoir pressure and separator pressure.

The average reservoir pressure and separator pressure constitute the endpoints of the system, and are the only fixed pressures in the system that do not vary with flow rate.

2. BASIC DATA NECESSARY FOR THE ELABORATION OF THIS PAPER

2.1. Fluid data and fluid properties; PVT correlations.

The most important parameters that must be used are: Condensate Gravity, Specific Gravity Gas, Condensate Yield, Liquid Yield, Water Cut, Specific Gravity, Salinity, Gas Impurities, Pseudo-Critical gas parameters.

For Pressure Volume Temperature (PVT) correlations we used models thermodynamics writing by:

- Gas viscosity: Lee Models [8];
- Water viscosity: Mathews & Russell Models [9, 10];
- Z factor: Drunchuk & Purviz models [11].

2.2. Production, field data and completion component.

For production and field data we used following parameters: measured gas flow, water flow, condensate flow, CO_2, H_2S, N_2 content and for field data: reservoir pressure, reservoir permeability and reservoir thickness [8, 12].

The completion component is a critical part of an efficient producing system, yet is often given little attention. It has been found that many wells have produced at less than optimum levels because of inadequacies in the completion design. There are a number of completion types for an oil or gas well.

The well depth, well type, and formation characteristics determine the choice of completion type to use in a case analysis.

3. HOW TO PERFORM SIMULATIONS

The productivity of the well depends on an efficient use of the compressional energy available in the reservoir allowing the reservoir fluids to flow toward the production separator. As an introduction to IPR and VLP, this article will introduce two key relationships (IPR and VLP) used in the design of the production system.

Inflow Performance Relationship (IPR) is defined as the well flowing bottom-hole pressure (Pwf) as a function of production rate. It describes the flow in the reservoir [5].

The Pwf is defined in the pressure range between the average reservoir pressure and atmospheric pressure. A typical inflow performance relationship is presented in the Figure 1.

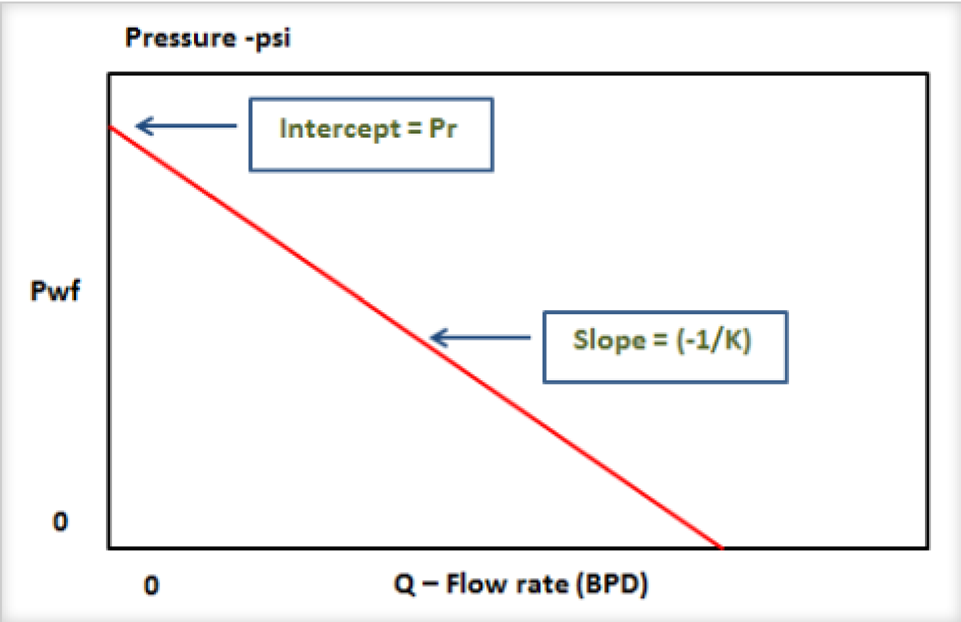

Figure 1. A typical IPR graph [4, 5]

The intersection of the PI plot with the x-axis is the flow rate corresponding to a Pwf equal to zero.

This point in the IPR plot is known as the *Absolute Open Flow* (AOF) potential of the well. Vertical Lift Performance Relationship (VLP), named also Outflow, describes the bottom-hole pressure as a function of flow rate (Figure 2).

The VLP depends on many factors including fluid PVT properties, well depth, tubing size, surface pressure, water cut and GOR. It describes the flow from the bottom-hole of the well to the wellhead.

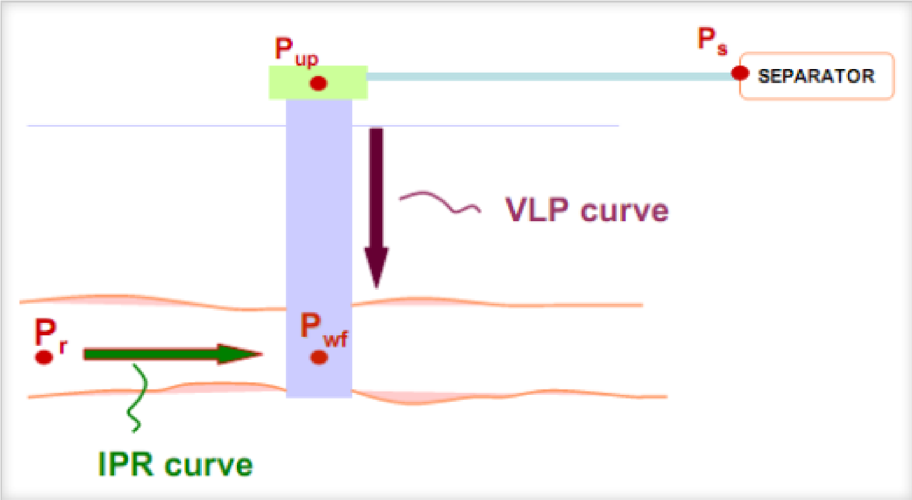

Figure 2. The flow from the bottom-hole of the well to the wellhead [6, 7]

Both the Inflow Performance Relationship and the Vertical Lift Performance Relationship relate the wellbore flowing pressure to the surface production rate. [11]

While the IPR (Figure 3) represents what the reservoir can deliver to the bottom hole, the VLP represents what the well can deliver to the surface. [11]

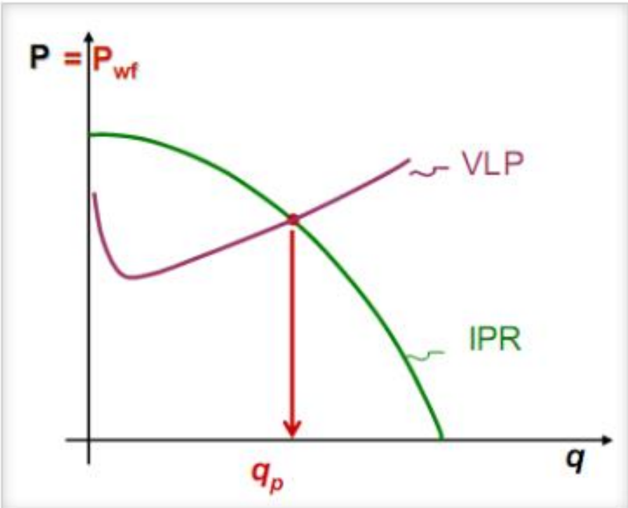

Figure 3. Solution Point (Pwf & Production Rate) [8]

The intersection of the IPR with the VLP, called **the operating point**, yields the well deliverability, an expression of what a well will actually produce *for a given operating condition (Pr, PI, WC, GOR, THP, Tubing size…)*.

4. SENSITIVITY STUDY

The production rate can be severely restricted even by the performance of a single component in the system.

If the effect of each component on the total system performance is isolated, the whole system can be optimized in the most economical way.

This sensitivity study allows to determine the production capacity for any combination of components in order to optimize the production.

In the following cases we focus on the effect introduced by perforation density, tubing size, flowline size, damaged zone permeability and damage zone radius.

In order to calibrate the program, the current situation of the operation of the well that is the object of the study-well M 07-through the Flow lineof 656 m length and with a diameter of 3 " was first simulated (Table 1 and Figure 4).

The results of the simulations are presented below together with the operation diagram of the well.

It can be seen that the simulation program is calibrated upon the functional characteristics of the studied well.

Table 1. Well M 07- effect introduced by perforation density M 07 Well data

Gas flow (measured)	98223	Nm^3/d	CO2 content	0.32	%
Water flow	0.2	m^3/d	H2S content	0	%
Condensate flow	0.9	m^3/d	N2 content	0.68	%
Reservoir pressure	36.2	bar	Perforation density	11	SPM
Reservoir permeability	510	mD	Perforation diameter	43	mm
Reservoir thickness	149	m	kc / kf ratio	0.6	
Perforation interval	7	m	Damaged zone permeability	62	mD
Reservoir temperature	56	ºC	Damaged zone radius	650	mm
Reservoir area	488	ha	Flow line length	656	m
Water density	1070	kg/m^3	Flow line diameter	52.5	mm
Condensate density	780	kg/m^3	Separator pressure	15	bar

The difference between the actual discharge of the well (98223 Nm^3/d) and that obtained by simulation (98498.2 Nm^3/d) is only 0.03% (Table 2).

In order accomplish the study, in addition to the current density of 11 perforations per meter, other 3 values of the perforation density were taken into account, respectively 16, 21 and 26 perforations per meter. The simulations of the well production flow in these new conditions were made. The results of the simulations are highlighted within the following table 3.

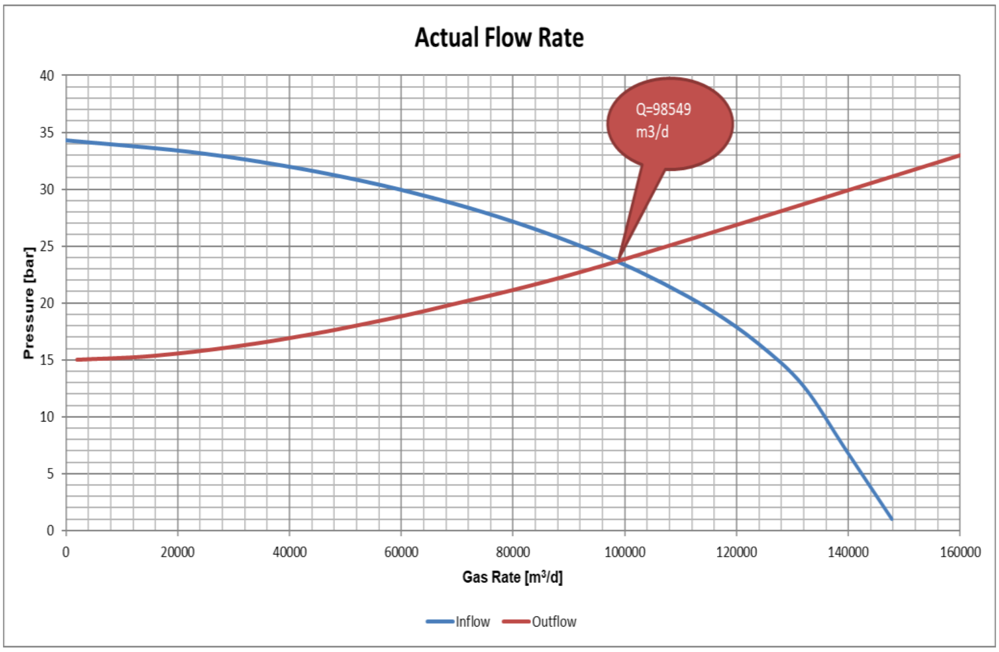

Figure 4. Diagram of operation at the current situation - M 07 well

Table. 2. Simulation results - current situation - M 07 well

Inflow (IPR)		**Outflow (VLR)**	
Discharge	**Pressure**	**Discharge**	**Pressure**
0	9.31	452.4	15
8456.2	62.97	2600.8	15
16521.7	63.09	3886.4	15.01
24246.0	64.45	5370.5	15.02
31668.8	62.77	7125.8	15.04
38822.9	60.97	9274.2	15.06
45735.4	59.04	12043.9	15.1
52429.1	56.93	15947.5	15.16
58923.5	54.7	22620.9	15.31
65235.4	52.34	40717.7	15.88
71379.2	49.85	60322.5	16.75
77367.6	47.20	82943.4	18.04
83211.8	44.37	105564.4	19.54
88921.7	41.31	128185.3	21.22
94506.0	37.98	150806.2	23.03
99972.8	34.28		
120795.3	9.10	Q =98498.2 Nm^3/d	
124810.9	1.01		

Table 3. Simulation results for the 4 perforation densities

Density SPM =11		**Density SPM =16**		**Density SPM =21**		**Density SPM =26**	
Discharge	**Pressure**	**Discharge**	**Pressure**	**Discharge**	**Pressure**	**Discharge**	**Pressure**
0	34.3	0	34.3	0	34.3	0	34.3
21750.7	33.31	39406.1	32.32	41212.9	32.32	66845.9	30.43
38681.2	32.09	66845.9	29.94	69651.6	30	108561.4	25.67
53034.6	30.73	89208.5	27.24	92767.3	27.42	141645.2	19.55
65717.1	29.23	108561.4	24.18	112745.7	24.53	169900.9	9.49
77202.2	27.6	125861.5	20.56	130590.7	21.16	193716.9	1.01
87774.9	25.82	141645.2	15.95	146862.7	16.88		
97622.2	23.88	156249.1	8.81	161912.3	11.02		
106874.7	21.72	172189.8	1.01	187621.8	1.01		
115627.9	19.31						
123954.2	16.4						
Q =98498.2 Nm³/d		Q =105428.7 Nm³/d		Q =108755.1 Nm³/d		Q =110454.5 Nm³/d	

Based on these results, the inflow and outflow diagrams were drawn for the flow of the biphasic mixture through the 3 inch pipe (Figure 5).

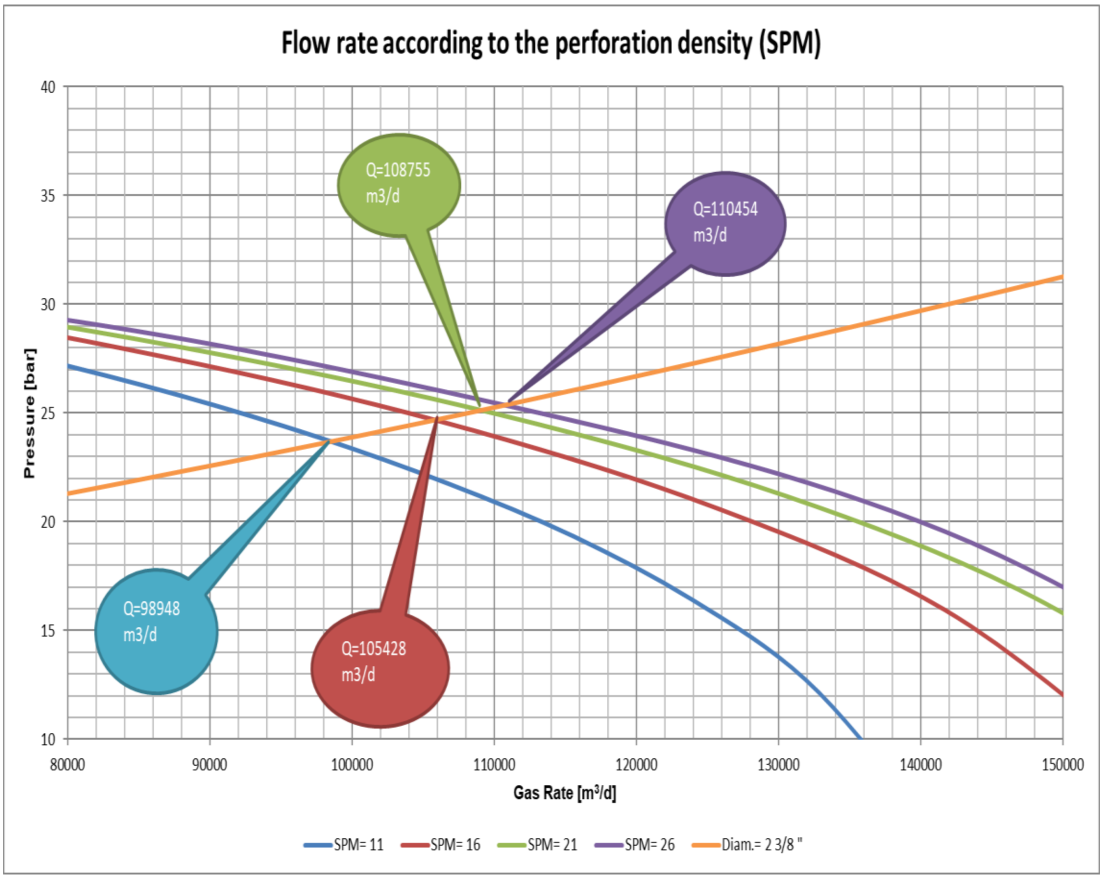

Figure 5. Graphic simulation results

4.1 Simulation results

In summary, the simulation results is presented in the table 4.

Table 4. Simulation results for M 07 well

Current Discharge	**Simulated Discharge**		
Density **SPM =11**	Density **SPM =16**	Density **SPM =21**	Density **SPM =26**
98498.2 Nm^3/d	105428.7 Nm^3/d	108755.1 Nm^3/d	110454.5 Nm^3/d
Effect	+7%	+10,4%	+12.1%

In order to calibrate the program, the current situation of the operation of the well that is the object of the study - well M 08 - through the mixing pipeline of 1820 m long and with a diameter of 3 inch was first simulated (Table 5).

Table 5. Well M 08- effect introduced by damaged zone permeability M 08 well data

Gas flow (measured)	51100	Nm^3/d	CO2 content	0.32	%
Water flow	1.2	m^3/d	H2S content	0	%
Condensate flow	1.5	m^3/d	N2 content	0.68	%
Reservoir pressure	27.1	bar	Perforation density	11	SPM
Reservoir permeability	746	mD	Perforation diameter	43	mm
Reservoir thickness	73	m	kc / kf ratio	0,6	
Perforation interval	6	m	Damaged zone permeability	41	mD
Reservoir temperature	48	ºC	Damaged zone radius	850	mm
Reservoir area	488	ha	Flow line length	1820	m
Water density	1070	kg/m^3	Flow line diameter	77.93	mm
Condensate density	780	kg/m^3	Separator pressure	15	bar

The results of the simulations are presented below together with the operation diagram of the well (Figure 6 and Table 6).

It can be seen that the simulation program is calibrated on the functional characteristics of the studied well.

Table. 6. Simulations results - current situation - M 08 well

Inflow (IPR)		**Outflow (VLR)**	
Discharge	**Pressure**	**Discharge**	**Pressure**
0	11.16	297.9	15
5967.7	22.75	1712.4	15
11569.9	22.17	2558.9	15.01
16866	21.54	3536.1	15.01
21901.2	20.87	4691.8	15.02
26710.4	20.16	6106.4	15.03
31321.2	19.42	7930	15.04
35736.3	19.01	10500.3	15.08
40034.1	18.48	14894.3	15.14
44170.0	17.80	26809.7	15.4
48177.3	17.25	39718.1	15.8
52067.1	15.95	54612.4	16.4
55849.1	14.51	69506.7	17.13
59351.5	12.88	84401	17.98
63121.9	10.97	99295.3	18.91
		Q =51109 Nm^3/d	

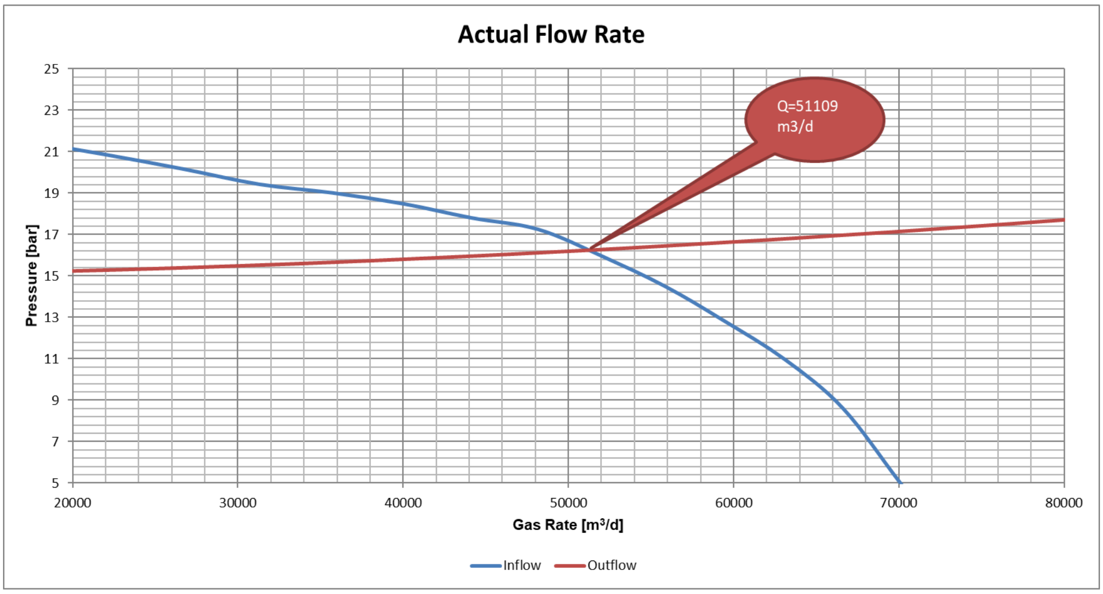

Figure 6. Diagram of operation in the current situation - well M 08

The difference between the actual flow rate of the well (51100 Nm^3/d) and that obtained by simulation (51109 Nm^3/d) is insignificant (Table 7).

In order to accomplish the study, in addition to the current permeability of 41 mD, other 3 values of it, respectively of 80 mD, 100 mD and 200 mD were taken into account.

The simulations of the production well flow were made in these new conditions. The results of the simulations are highlighted in the table 7.

Based on these results, the inflow and outflow diagrams were drawn for the flow of the biphasic mixture through the 3 inch pipe (Figure 7).

Table 7. M 08 well simulation results

k=41 mD		**k=80 mD**		**k=100 mD**		**k=200 mD**	
Discharge	**Pressure**	**Discharge**	**Pressure**	**Discharge**	**Pressure**	**Discharge**	**Pressure**
0	11.15	0	11.16	0	11.16	0	11.16
5967.7	22.75	11445.6	22.74	14219.2	22.73	34841	22.38
11569.9	22.17	21676.5	22.11	26650.1	22.06	61628.7	21.15
16866	21.54	31011.2	21.41	37831.6	21.32	84204.5	19.71
21901.2	20.87	39649.5	20.66	48076.2	20.52	104073.5	17.59
26710.4	20.16	47726	19.85	57584.3	19.65	122012	14.01
31321.2	19.42	55337	19	66493.6	18.82	138482.8	6.76
35756.3	19.01	62554	18.34	74903.4	17.69	151545.4	1.01
40034.1	18.48	69431.7	17.21	82888.2	16.15		
44170	17.8	76013.4	15.75	90505.7	14.12		
48177.3	17.25	82333.8	13.89	97801.5	11.34		
52067.1	15.95	88421.1	11.62	104812.5	7.52		
55849.1	14.51	94299	8.59	116778.1	1.01		
59531.5	12.88	99987.4	2.75				
63121.9	10.97	101684.1	1.01				
Q=51109.2 Nm^3/d		Q= 69443.4 Nm^3/d		Q= 75509 Nm^3/d		Q= 94017.3 Nm^3/d	

The simulation result is briefly presented in the table 8.

Table 8. Simulation result for M 08 well

Current flow rate	**Simulated flow rate**		
Permeab. 41 mD	Permeab. 80 mD	Permeab. 100 mD	Permeab. 200 mD
51109.2 Nm^3/d	69443.4 Nm^3/d	75509 Nm^3/d	94017.3 Nm^3/d
Effect	+35.87 %	+47.74 %	+83,95 %

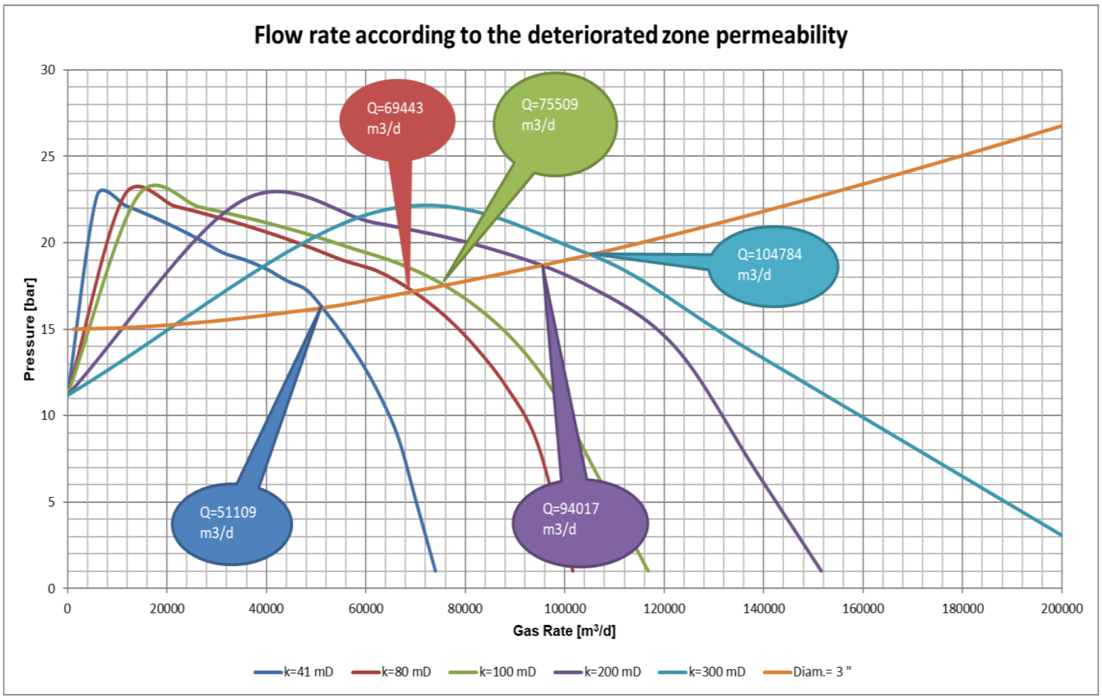

Figure 7. Graphic simulation results

5. CONCLUSIONS

Increasing the permeability of the damaged adjacent area of the well leads, as expected, to an increase in the gas flow of the well.

However, this increase is spectacular, making the method attractive from the start. However, due to the difficulties in increasing the permeability of the area adjacent to the well, it can only be taken into account just on the basis of an economic calculation.

Case A. Increasing the perforation density of the well leads, as expected, to an increase of the gas flow of the well.

This increase is not spectacular but can be taken into account on the basis of an economic calculation.

Case B. There is a spectacular increase in the flow rate of the gas well with the increase of the damaged zone permeability.

An economic calculation is necessary due to the high costs for the stimulation operations.

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