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# EVALUATION OF THE DAMAGE SOURCE IN HYDOCARBON PRODUCING WELLS TO INCREASE THE PERFORATION EFFICIENCY

Besides the behavior of the hydrocarbon reservoir, the drilling and completion technology has a significant influence on the production capacity of oil and gas wells. When a well is not producing as expected, the formation may have low permeability or/and may be “damaged”. If the evaluation of the well productivity during the DST (Drill Steam Test) tests and the production of other wells in the same reservoir show that the production of the examined well should be higher we can look for the reason for the low production.

If the reservoir permeability is low the well is the candidate of the stimulation by hydraulic fracturing. When the restricted flow into the wellbore caused by the improper well drilling or well completion technology then the near wellbore damage should be removed or decreased, and the completion technology should be corrected.

In order to increase the efficiency of well completion and select the right well stimulation method we need to recognize the reason for the low production. After recognizing the source of low production we will be able to increase the well production by selecting and applying the suitable well stimulation method and we will be able to correct our drilling and completion technology in other to increase the production of the wells that will be drilled in the future.

## 1. DAMAGES AROUND THE WELLBORE

The improper drilling and wellbore completion technology causes many serious damage around the well, especially in the near wellbore zone. Later in the life of the well, the production, the injection and the stimulation also can cause some damage around the well that will reduce the production of the well.

The reason for the low production of a well can be one or some of the following:

- change in permeability near the wellbore “formation damage”
- change in radial flow geometry, caused by limited entry to wellbore (limited completion interval) and flow convergence into the perforations
- perforation effects
- high velocity flow (turbulence mainly at the near wellbore zone)
- saturation blockage near wellbore
- improper sand control or flow restriction caused by the proper sand control.

It is widely accepted in the petroleum industry that these effect can be considered through the composite pseudo skin factor.

### *1.1 Change in permeability near the wellbore ("formation damage")*

The near wellbore damage is usually caused by improper drilling or completion technology. During drilling, overbalanced condition results in influx of fluids and solids from the wellbore into the formation. The volume of invading fluids is usually small and the invasion is limited to short distances, i.e. a few inches to a few feet from the wellbore. The depth of solids invasion is less than fluid invasion and usually is limited to a few inches only. The invading fluids and solids interact with the formation and formation fluids, creating a multitude of productivity damage effects. These different effects and their location around the wellbore can be seen on **Figure 1**.

We can reduce these damages if we change our drilling technology (i.e. we change drilling mud properties, and change the washing fluid properties before cementing).

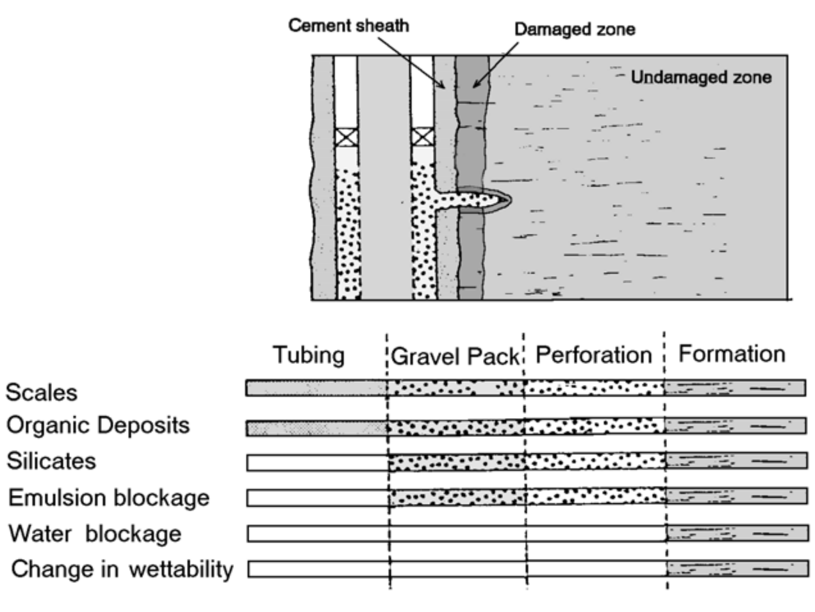

**Fig. 1. Damages around the wellbore and their locations.**

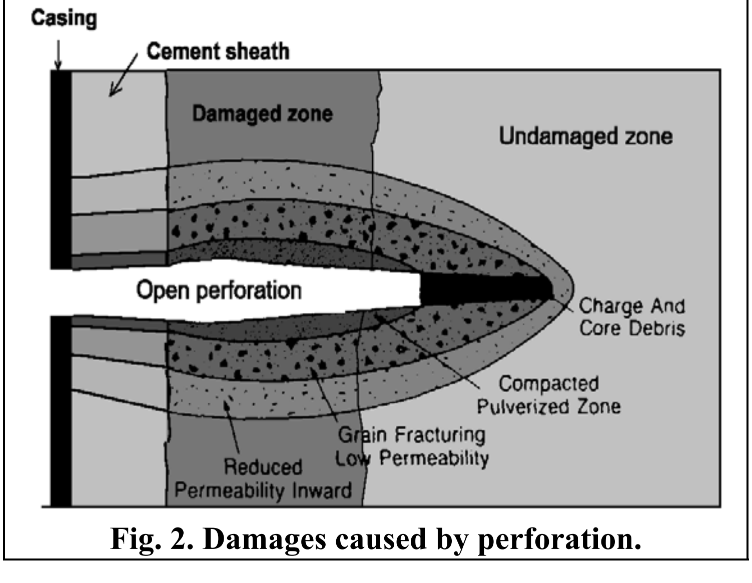

**Fig. 2. Damages caused by perforation.**

### *1.2 Damages during perforation*

The perforation of cased wells is one of the important elements in well completion technology. Perforating is always a cause of additional damage to the formation. Whether it is performed overbalanced or underbalanced, it always compacts the rock around the perforations and produces a zone with an average thickness of 10 mm where the permeability reduction averages 80% as we can see in **Figure 2.** There are many other factors that can further reduce well productivity:

- Perforating overbalanced always forces formation and gun debris into the perforation walls and decreases the permeability near the perforation.
- Perforating overbalanced in fluids that contain particles produces a similar effect and also builds a dense, impermeable cake on the perforation wall.
- Insufficient perforation penetration that has not bypassed drilling damage.
- Incorrect estimate of underbalance pressure required to achieve damage–free perforation. Insufficient pressure differences limit damage removal. Excessive differences lead to sand influx in the wellbore.

Considering the above-mentioned effects we can select a better perforation geometry and perforation technology.

### *1.3 Change in radial flow geometry and high velocity flow*

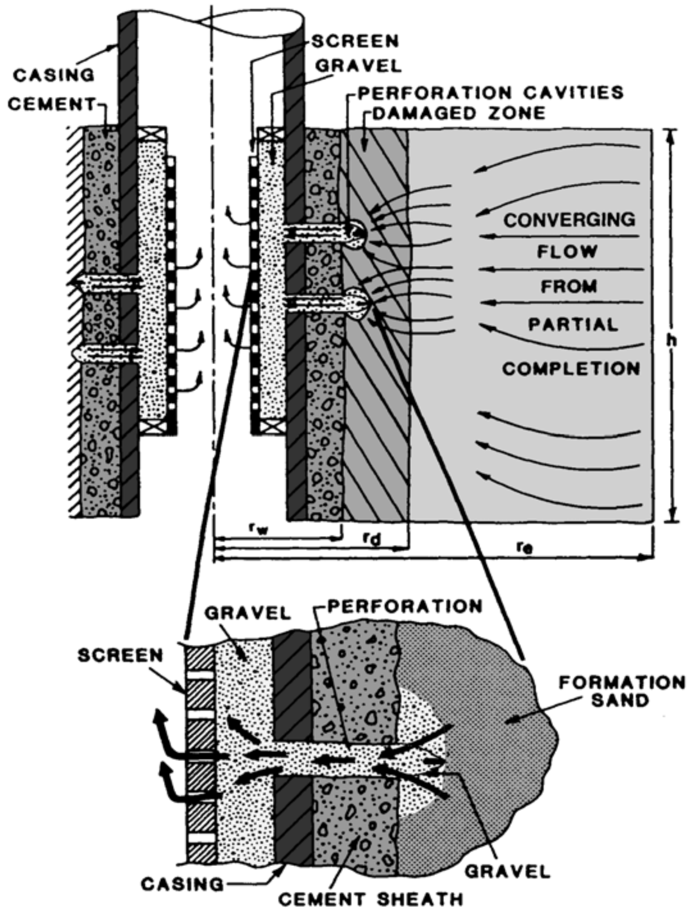

**Fig. 3. Flow convergence around the well.**

Change in radial flow geometry, caused by limited entry to wellbore (limited Completion interval) and flow convergence into the perforations also cause additional pressure drops around the wellbore. These additional pressure drops reduce the productivity of the well. High velocity flow (turbulence mainly at the near wellbore zone) also causes pressure drop and decreases the well productivity. These flow convergence effects can be sees on **Figure 3.** We can consider these additional inflow restrictions (caused by flow convergence and turbulence) with so-called pseudo-skin factors.

We can reduce this production decrease by increasing the perforation length and changing the perforation geometry and technology.

## 2. ESTIMATING THE EFFICIENCY OF WELL COMPLETION

In the petroleum industry the productivity ratio is used to characterize productivity of a well. According to Schlumberger [1] the productivity ratio is calculated as:

$$PR=\frac{ln\left(\frac{r_e}{r_w}\right)}{ln\left(\frac{r_e}{r_w}\right)+s} \tag{1}$$

where skin factor **s** should be considered as a pseudo-skin factor, $\mathbf{r_e}$ is the drainage radius, and $\mathbf{r_w}$ is the well radius (drilled wellbore radius) in m.

**Equation 1** is derived by dividing the flow rate of the damaged well by the "perfect well's" flow rate, while the other parameters are constant. The flow rate of a perfect well means the flow rate of an ideal well opening an undamaged reservoir layer in its entire thickness.

*We suggest that instead of the* ***productivity ratio*** *the so-called* **perforation productivity ratio PPR** *[2] should be used to characterize the efficiency of the well completion.*

The perforation productivity ratio defines the flow rate of the open hole well in relation to the flow rate of the completed (perforated) well. The length of the open section of the uncased well equals the length of perforation in the completed well. The **PPR** is determined by the following relationship:

$$PPR=\frac{ln\left(\frac{r_e}{r_w}\right)-0.75+s_1}{ln\left(\frac{r_e}{r_w}\right)-0.75+s_2}. \tag{2}$$

In this equation the skin factor $\mathbf{s_1}$ does not include the effect of well completion, but includes the effects of the flow line convergence caused by the limited entry, $\mathbf{s_2}$ is the measured skin factor after perforation. Considering all effects during drilling, cementing, and perforation of the well, $\mathbf{s_1}$ and $\mathbf{s_2}$ are determined by the following two relationships:

$$s_1=s_c+s_A+\frac{h}{h_p}s_a+s_b+\left(D_R+D_a\right)\cdot q \tag{3}$$

$$s_2=s_c+s_A+s_{dp}+\frac{h}{h_p}s_a+\frac{h}{h_p}s_p+s_b+s_G+\left(D_R+D_a+D_{dp}+D_G\right)\cdot q \tag{4}$$

where

| | |
|---|---|
| $\mathbf{s_c}$ | the skin factor considering the partial penetration and limited entry |
| $\mathbf{s_A}$ | the outer boundary geometry skin, |
| $\mathbf{s_G}$ | the gravel-pack skin, |
| $\mathbf{p_d}$ | the skin factor due to a reduced crushed-zone permeability, |
| $\mathbf{s_p}$ | the perforation skin, |
| $\mathbf{s_a}$ | the skin factor caused by permeability alteration near the wellbore, introduced by Craft and Hawkins, |
| $\mathbf{s_b}$ | the blockage skin caused by the phase change near well, |

| | |
|---|---|
| $\mathbf{D_R}$ | the turbulence factor due to the high-velocity flow in the region beyond near wellbore damage, $s/m^3$ , |
| $\mathbf{D_a}$ | is the turbulence factor due to the high-velocity flow in the altered permeability zone (demigod or stimulated), $s/m^3$, |
| $\mathbf{D_{dp}}$ | the turbulence factor due to the high-velocity flow in the damaged zone surrounding the perforation channels, $s/m^3$, |
| $\mathbf{D_G}$ | the high-velocity flow term in a gravel-packed perforation, $s/m^3$, |
| $\mathbf{q}$ | the fluid flow rate of the well, $m^3/s$, |
| $\mathbf{h}$ | the effective (pay zone) thickness, m, |
| $\mathbf{h_p}$ | perforation interval, m. |

The skin and turbulence factors in **Equations 3 - 4**. can be calculated by the equations given in reference [3]. In case of an actual well only those effects have to be taken into account that actually reduce the well production. For example, if the well is completed without gravel-pack, the terms $\mathbf{D_G}$ and $\mathbf{s_G}$ must not to be taken into account in the calculations.

The use of perforation productivity ratio **PPR** has an advantage that its application enables one to examine the effects of well completion. The introduction of the **PPR** can also be justified on the one hand, that we cannot drill perfectly damageless wells with present drilling technology; and on the other hand, that the above mentioned skin and turbulence factors include such terms that contribute to the restriction of well production even if it has an open hole interval. (For example the outer boundary skin $\mathbf{s_A}$, or the turbulence factor due to the high-velocity flow in the demigod zone $\mathbf{D_a}$.) The pseudo-skin factors $\mathbf{s_1}$ and $\mathbf{s_2}$ can also be calculated by other equations published in the technical literature. Depending on how accurate one can or want to consider the production restriction effects taking place in the well, different relationships could be used.

## 3. EXAMPLE

In the following example, well test data of the **Üllés 61** oil well were used to calculate the value of **PPR**. A **NODAL analysis** calculation was performed on a computer, using the measured and calculated production, pressure, permeability, and skin values, obtained during the well test.

During calculations, assumed perforation parameters were varied until the calculated production rate and the pseudo-skin became equal the production and skin values obtained from the well test. This parameter matching was necessary because there was a lot of estimated parameters in **Equations 3, 4** that could not be obtained with other methods, for example the length, diameter of the perforation channel, and the thickness and permeability of the surrounding crushed zone. After parameter matching the well was assumed to be completed with open hole with a length corresponding to the perforation length. The production of the well under these conditions was calculated next. Dividing the measured flow rate of the well by the last calculated production, the value of **PPR** could be determined. Input data and calculation results can be seen in **Table 1.** The measured fluid production of the perforated well was 213.8 $m^3$/day, and the production of the open hole completion was 272.1 $m^3$/day. The calculated perforation productivity ratio, **PPR** was found as 78.6%.

After an analysis of the results it can be stated that perforation penetration length had the greatest influence on the production of the well at hand. Increase in **PPR** and production reached about 22%. In contrast to this, significantly increasing the shot density would mean only a 6.6% increase, and the change of phasing would result only in a 3.7% increase in well production. The effect of the shot density of the perforation is shown in **Fig. 4**. The effect of the perforation penetration length on well production is shown in **Fig. 5**.

**Table 1.**

Data and results of the parameter matching of well **Üllés 61**.

| | |
|---|---|
| Gas oil ratio $m^3/m^3$ | 42.4 |
| Specific density of oil,(water=1) | 0.71 |
| Gas specific gravity- | 0.715 |
| Tubing length, m | 2340 |
| Tubing diameter, m | 0.062 |
| Flow line length, m | 3250 |
| Flow line diameter, m | 0.06 |
| Separator pressure, MPa | 2.1 |
| Reservoir temperature, °C | 147 |
| Reservoir pressure, MPa | 34.72 |
| Net pay thickness , m | 11 |
| Perforation length, m | 11 |
| Well radius, m | 0.089 |
| Reservoir permeability, $10^{-15}$ $m^2$ | 21.3 |
| Shot density, shots/m | 14 |
| Phasing, ° | 0 |
| Total fluid production, $m^3$/day | 213,8 |
| *Vertical permeability, mD | 5.7 |
| *Perforation channel diameter, m | 0.01 |
| *Perforation penetration, m | 0.2 |
| *Damaged zone radius, m | 0.6 |
| *Damaged zone permeability, mD | 7.0 |
| *Crushed-zone thickness, m | 0.01 |
| *Crushed zone permeability, mD | 5.0 |

* These values were found from parameter matching.

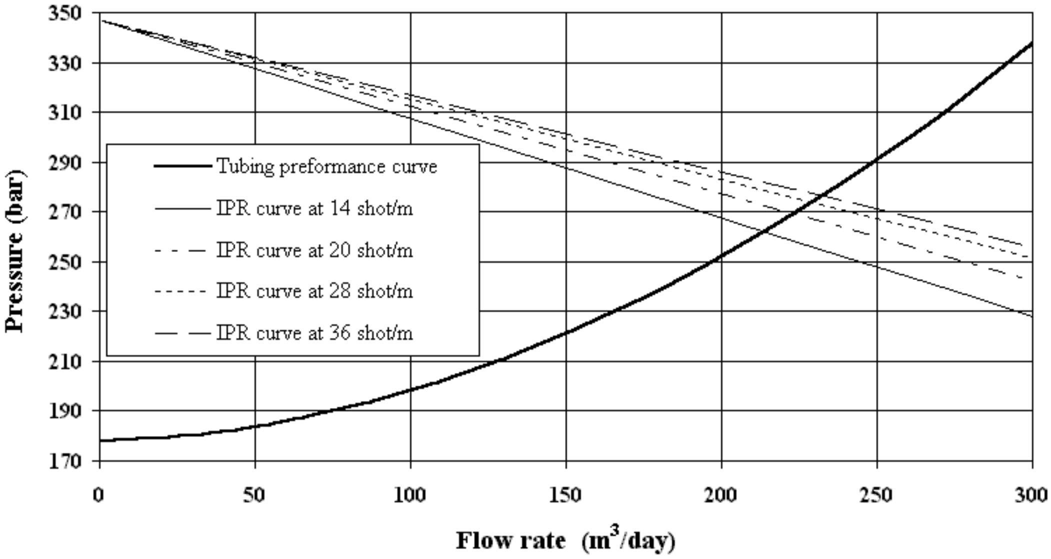

Fig. 4. Effect of shot density on well production.

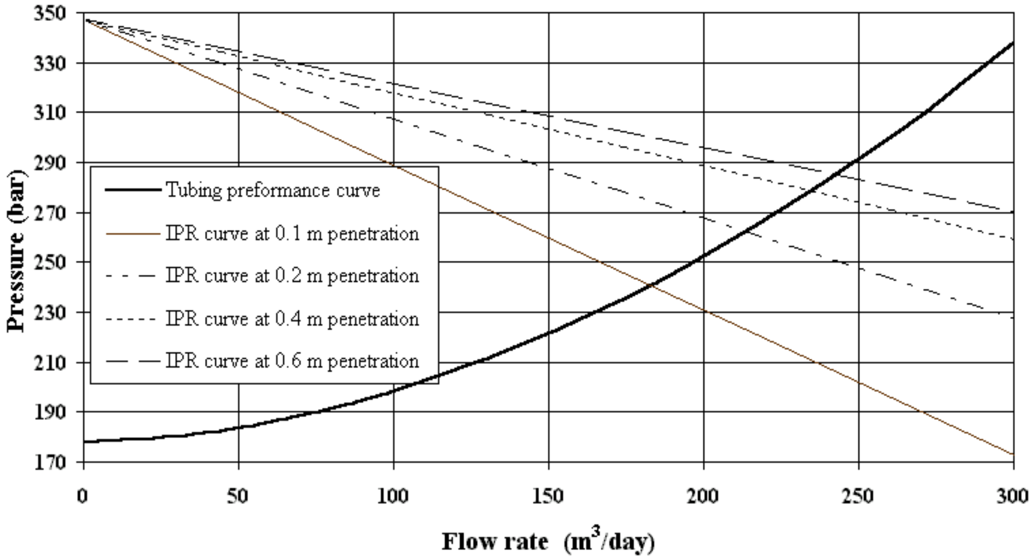

Fig. 5. Effect of the perforation penetration on well production.

The effect of phase angle of the perforation on well production is shown in **Figure 6**.

Theoretically, the **PPR** value calculated in the basic case could be obtained as the ratio of the measured flow rate of the perforated well and the flow rate of the well measured on the perforation interval in the uncased well (during a **DST** test). But this is not true because, on the one hand, the drillstem test is not suitable - because of the short measuring time - for measuring of pseudo steady-state production. On the other hand, before perforating the casing, it must be cemented and that cause additional damages in the near wellbore zone, too. So the damage in the near wellbore zone during a drillstem test differs from the damage that exists in the completed well before perforation. The last-mentioned condition can be considered as a reference state at the calculation of the

**PPR** factor. So with the shown calculation method the perforation efficiency can be examined separately.

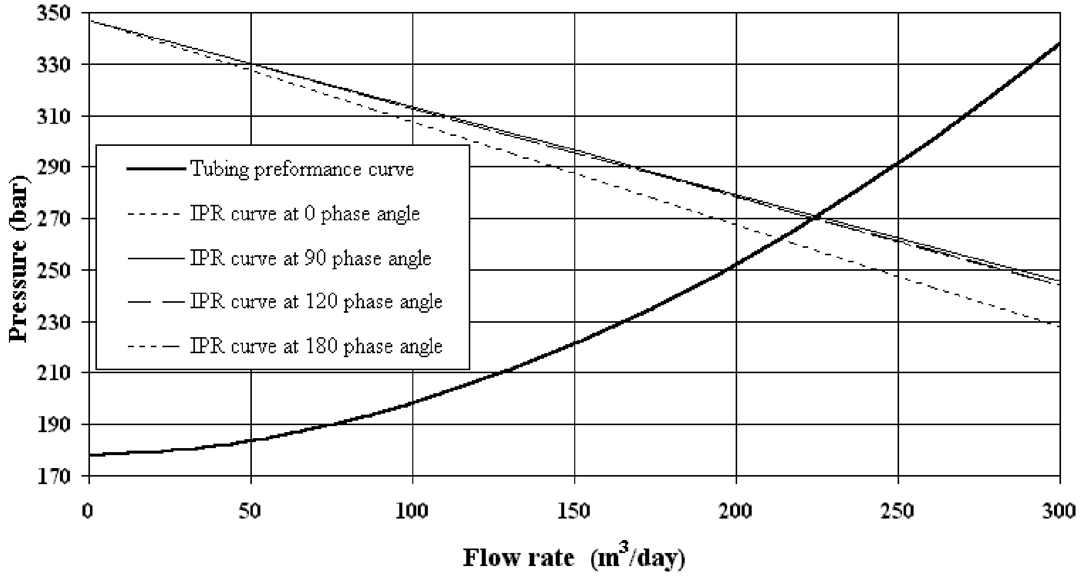

Fig. 6. Effect of the perforation phase angle on well production.

Analyses of the results calculated by NODAL analysis give an opportunity to select the most efficient perforation and well completion method for given reservoir conditions. The new well completion method can be applied in the future.

## REFERENCES

1. Cased Hole Log Interpretation Principles/Applications. Schlumberger Education Services, Houston, Texas 1989
2. T. Bódi: Evaluating the Efficiency of Jet Perforations. 9-th International Scientific and Technical conference. New Knowledge in Sphere of Drilling, Production and Gas Storages. pp 19-23 Podbanské (Solvakia) 8-10. October 1996.
3. M. Golan, C. H. Whitson: Well Performance. P T R Prentice Hall Inc. Englewood Cliffs, New Jersey 1991
4. M. J. Economides, K. G. Nolte: Reservoir Stimulation. Schlum-berger Educational Services 5000 Gulf Freeway Houston, Texas 77023. 1989
5. S. M. Tariq, M.J. Ichara, L. Ayestaran: Performance of Perforated Completions in the Presence of Anisotropy, Laminations, or Natural Fractures, *SPE Production Engineering*, (November, 1989) pp. 376-384.