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An Efficient Method for Enhanced Oil Production Providing an Increase in Oil Recovery Index

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Abstract

PEnTechnology was developed for high-GOR oil fields. The target was the optimization of well-formation system by means of maintenance of bottomhole pressure and supporting fluid lift. The technology applies an individual approach to each well, based on analysis of nymerous parameters and data, computer simulation of well-formation system and sizing calculation for the technology's bottomhole tools.

Introduction

In oil fields with relatively high gas/oil ratio (GOR) of more than 600 scf/bbl well productivity declines vary rapidly due to the following processes. When bottomhole pressure decreases below saturation pressure, oil degasses in the near bottomhole zone of the reservoir. The liberated gas blocks the zone, affecting relative oil permeability. Such negative processes evolve over months, even years, causing a significant decrease in oil production and recovery index.

PEnTechnology prevents or minimizes the above-mentioned negative processes, provides and increase in daily oil production and recovery factor. Fig.1 illustrates the PEnTechnology's influence on oil mobility and gas and water coning near the wellbore.

PEnTechnology performs most efficiently in reservoirs with a developed solution gas drive, water drive, or combination thereof, with an intensive gas and water coning. Application of PenTechnology is highly recommended for the wells declining oil production and increasing GOR.

Principle Theory and the Tools

PEnTechnology optimizes operational regime of the well-formation system in accordance with current status of the oil field, in order to increase both daily oil flow rates and total oil recovery from the reservoir. At the same time, the reservoir energy is being preserved for the well to operate over an extended period of time with higher flow rates. These goals are achieved by the set up and maintenance of the bottomhole pressure at an optimum calculated level, by means of a bottomhole tool, and by supporting fluid lift within the well by means of a wellhead regulator. The bottomhole tool carries out the main functions. It is a multiparametric system of small-diameter tubes and nozzles. The tools are custom made for each well, with individual design, configuration and size, according to the computer simulation of the well-reservoir system. PEnTechnology's bottomhole tool has a flat dependence of $\Delta P=f(Q, GOR)$, characterized by a stable pressure gradient ΔP between its inlet and outlet within a wide range of fluid flow rates (Q) and GOR. A supplementary function is served by a wellhead regulator, which maintains an optimum pressure within the tubing, in order to prevent occurrence of an annular mist in the well.

PEnTechnology operated successfully in oil fields of the Western Siberia, Texas and Louisiana, on- and offshore.

Well history

The demonstration of PEnTechnology was performed in an offshore well in the Gulf of Mexico (conventionally the "A" well). The exploitation began in 1991. The productive formation of the oil field is located at the depth of 5484-5514 ft. The reservoir is represented by sandstone with porosity of 25% and permeability of 184mD. Oil gravity was 26.6°API. The initial GOR = 530scf/bbl. The well recovers oil from a separate block.

Fig. 2 illustrates an average monthly oil production from June, 1991 through February, 1998 and the prognosis until July, 2003. Initially, for about 1 month, the well was producing approximately 1000 BOPD. Then, for approximately a year, flow rates were ~ 400 BOPD. For the following 5 years, since installation of gas lift, oil flow rates were maintained at a level of approximately 200 BOPD. In 1997 oil flow rates decreased to 160 BOPD, and several days

before the installation of PEnTechnology they were equal to 121 BOPD. From the beginning of well operation, up to the date of installation of PEnTechnology, GOR and WC were gradually growing, having reached more than 700 scf/bbl and 28% respectively.

Results

After the installation of PEnTechnology on September 24, 1997, oil flow rates initially decreased. In just one week oil flow rates again increased to a production level higher than before the installation of PEnTechnology. During the last month of the demonstration, from November 12, 1997 to December 13, 1997, the well was operating with an average flow rate of 177 BOPD. Fig. 3 illustrates operational parameters of the well from October, 1997 through March, 1998.

It is necessary to note that it takes a certain period of time, after the installation of PenTechnology, to establish an optimum operationl regime of a well. During that period the technology influences the negative effects, which have accumulated in the reservoir during the years of the previous well operation, and restores the reservoir energy. In well A the optimum regime was established by the 50th day after the installation of PEnTechnology, on November 12, 1997. Should we take into consideration a 12-day shut-in (October 18 – November 1), due to non-related to the demonstration reasons, the optimum regime was established by the 38th day of operation. Table 1 illustrates the results of 2.5-month demonstration in well A, devided into three stages.

As a result of PEnTechnology's influence during establishment of the optimal regime in the well:

- oil flow rates increased by 35%
- the wellhead choke diameter was reduced from 64/64" to 20/64"
- wellhead pressure increased by 50%
- water cut reduced from 28% to 22%
- GOR decreased three times
- gas injection was decreased by 50%.

The above mentioned parameters clearly illustrate that, due to PEnTechnology, performance of the well and reservoir conditions were improved considerably within a wide drainage area:

- oil saturation and permeability of the reservoir drainage area have improved;
- hydraulic link of the well with the remote reservoir zones has improved;
- formation energy has restored, which would have prolonged the well life and increased recovery index provided PEnTechnology remained operational;
- the process of reservoir restoration was accompanied by increased oil flow rates, which could have been maintained for several more years, provided PEntechnology remained operational.

It is necessary to note, that during the demonstration period, October 18-31, 1997, the well was shut in due to repair works on another platform. (Fig.3) After the well was opened, its oil flow rates escalated to more than 300 BOPD. These rates were considerably higher than the maximum oil rates in July, 1997 (~ 200 BOPD) after the well had been shut-in for a considerably longer period – for about 3 weeks. In addition, in October water cut was maintained at a level of less than 20%, while GOR was decreased to 360 scf/bbl. For 12 days, following the shut-in peak, oil flow rates decreased to 169 BOPD (11/27/97). For the following month the well was producing 177 BOPD on average, with WC at a level of 16-24% and GOR of 237 scf/bbl. Performance of the well after the October shut-in, in comparison with the previous similar experience, proved the PEnTechnology's energy-restoring influence on the reservoir.

On December 13, 1997 the PEnTechnology's bottomhole tool was removed from the well. After the removal, oil flow rates abruptly increased to 400 BOPD. It must be emphisized that this peak of the increased flow rates was not a result of a shut-in, as it occurred on October 31, 1997. Instead, it was a direct result of the removal of the PEnTechnology's bottomhole tool. Approximately 7730 barrels of oil were produced during the month following the removal of PenTechnology, 3600 barrels of which represented the total additional production of oil. For a comparison: for the first 9 months of 1997 the average monthly oil production was 4130 barrels.* Only 5 years ago the well was perfroming at this rate, after gas lift was installed and when the reservoir pressure was considerably higher. Later, oil flow rates gradually reduced, and on February 26, 1997 they reached 128 BOPD. Notwithstanding the efforts of the oil company, operating the well, to optimize well operation by manipulating the gas lift, after PEnTechnology was removed, the oil flow rates were further decreasing without ever accomplishing the level achieved with PEnTechnology. It is evidenced by a rapid increase in water cut (to 32-36%) and GOR (to 800-1050 scf/bbl), which are considerably higher than before the installation of PEnTechnology in September, 1997. (Table #1)

One of the main parameters, illustrating the efficiency of PEnTechnology, is the diameter of the wellhead choke: with PEnTechnology the well was operating at 20/64" choke with wellhead pressure of about 210 psi, and after PEnTechnology was removed, at the diameter of 64/64" with wellhead pressure of 110 psi.

>*Without* PEnTechnology: the well can produce the maximum of 128-142 BOPD. In the meantime, the reservoir energy is being wasted. Oil flow rates will further decrease rapidly, while water cut and GOR will grow. The negative processes resumed evolving in the reservoir.

>***With*** PEnTechnology: the well has been operating with higher oil flow rates, while the reservoir was accumulating potential energy. No other existing technology can provide such effect.

* Compare this amount with approximately 1000 barrels, produced after the 12-day shut-in (Peak 1, Fig.1), which should not be considered the "additional" production as it corresponds to the well production at an average flow rate of 83 BOPD for the period of shut-in.

The amount of oil, additionally produced after the PEnTechnology's bootomhole tool was removed, represents the result of our technology's influence on the reservoir: reservoir energy was being preserved due to reduced water cut and GOR, an efficient increase in oil recovery due to an improved oil permeability of the formation and reduction of gas and water coning.

During the demonstration, PEnTechnology optimized operation of the well. Producing more oil daily, the formation kept on preserving its energy. In case PEnTechnology remained in the well, its operational life would have been extended, and the depletion curve would have been flatter. As an option, we could have chosen to maintain an expedited regime of oil production, similar to the regime of the well A operation for 3 days before the removal of PEnTechnology, when daily oil production was 215 barrels, diameter of the wellhead choke - 28/64", tubing pressure - 157 psi, water cut – 16% and GOR – 360 scf/bbl.

The rate of daily oil production with the installed PEnTechnology is directly proportioned to the intensity of the solution gas drive, having been developed before the installation of PEnTechnology. In case of a developed solution gas drive, installation of PEnTechnology provides an improvement for the drainage zone and oil permeability of the reservoir, as well as an increase in daily oil production.

In case of a water drive, PEnTechnology establishes a balance between oil-water contact and oil inflow into the well. It is possible to continuously maintain high flow rates due to established constant pressure differential between pressure at the contour of the formation and at the bottomhole.

An increase in oil recovery index was estimated the following way. Tectonic block of this oil field is being drained by one well only – well A. The recoverable resources can be estimated, using a graphic of monthly oil production in dependence to cumulative oil production[1]. (Fig.4) From 1992 the dependence is a straight line (linear production decline). By extrapolation of this linear decline to economically feasible oil flow rates (30-35 bbl/d), we can estimate the recoverable resources of this oil field of 620,000 – 650,000 barrels. The cumulative oil production is 460,000 barrels. The estimated remaining recoverable resources are 160,000 – 190,000 barrels. If PEnTechnology would have remained operating in this well, it would be possible to additionally produce approximately 72,000-100,000 barrels of oil, having increased the recovery index by 10-15% (by ~ $1,000,000-1,500,000, at $15 per 1 barrel of oil).

Conclusions

The results of 2.5-month demonstration of PEnTechnology provide an opportunity to visualize the current increase in the recovery index.

As a result of the demonstration:

- oil flow rates were increased
- wellhead choke diameter was decreased
- wellhead pressure was increased
- water cut reduced
- GOR decreased
- the amount of injection gas was reduced
- oil saturation and permeability of the near bottomhole zone of the formation inmproved
- hydraulic link of the well with distant zones of the formation improved
- reservoir energy restored, which provided an extention of well life and an increase in oil recovery factor
- well and reservoir restoration was accompanied by increased oil flow rates, which could have been maintained for several more years, provided PEnTechnology remained in operation.

Nomenclature

GOR – gas/oil ratio
Δ - gradient
P - pressure, psi
Q - oil flow rates, BOPD
WC - water cut in the production, percent.

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References

1. Laherrere, Jean H.: "Production decline and peak reveal true reserve figures," *World Oil* (Dec.1997) 77.

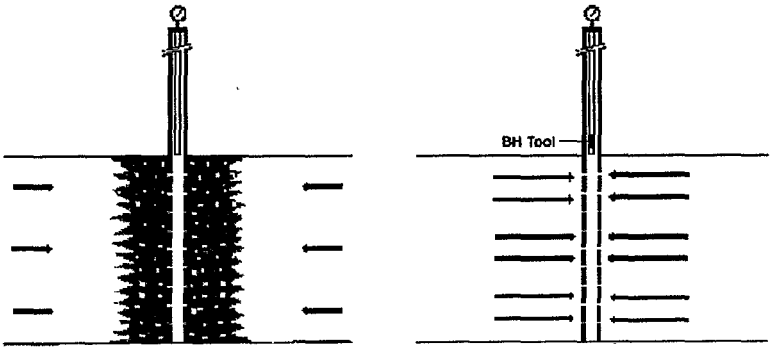
SI Metric Conversion Factors

°API 141.5/(131.5+°API)= g/cm^3
bbl ×1.589 873 E-01 = m^3
ft^3 ×2.831 685 E-02 =m^3
°F (°F-32)/1.8 =°C
in ×2.54 E+00 =cm
psi ×6.994 757 E+00 =kPa

TABLE 1 - COMPARISON OF MAIN PARAMETERS OF 3-STAGE WELL OPERATION

Parameters	9.23.97 1day before the installation of PEnTechnology tool	12.12.97 2.5 months after installation, 1 day before the removal of PEnTechnology tool	2.26.98 2.5 months after the removal of PEnTechnology tool
Oil, BOPD	121	164	128
Bottomhole Pressure, psi	765	1123	653
Choke, in.	64/64	20/64	64/64
Flowing Tubing Pressure, psi	140	210	122
Water Cut, %	28	22	33
GOR, scf/bbl	710	237	990
Injection Gas, Mscf/d	360	240	400
Specific rates of the injection gas, scf/bbl	2143	1141	2094

Positive influence of PenTech on oil mobility in near botomhole zone.

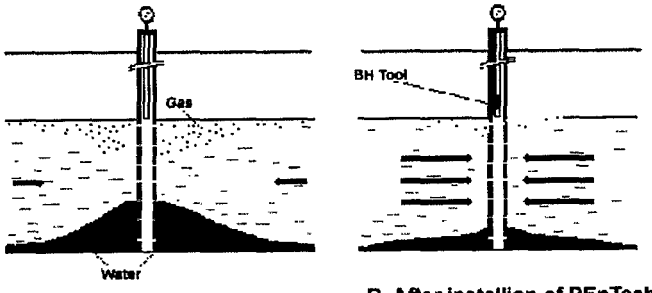


A. Before installion of PEnTech

B. After installion of PEnTech

Low oil permeability zone, as result of increased gas saturation of the formation and oil viscosity

Positive influence of PEnTech on gas and water coning.



A. Before installion of PEnTech

B. After installion of PEnTech

Fig. 1 - Positive influence of PEnTech on well performance.

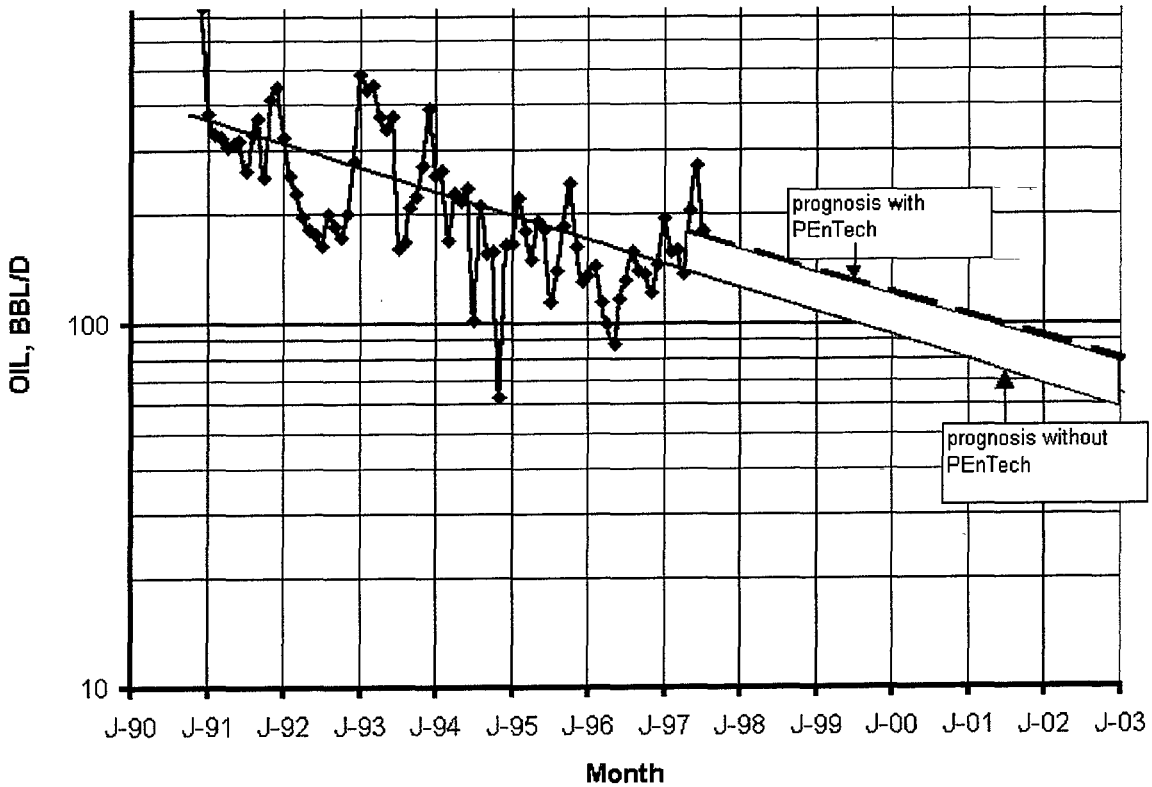


Fig. 2 - Average monthly oil flow rates from june 1991 through february 1998 and prognosis.

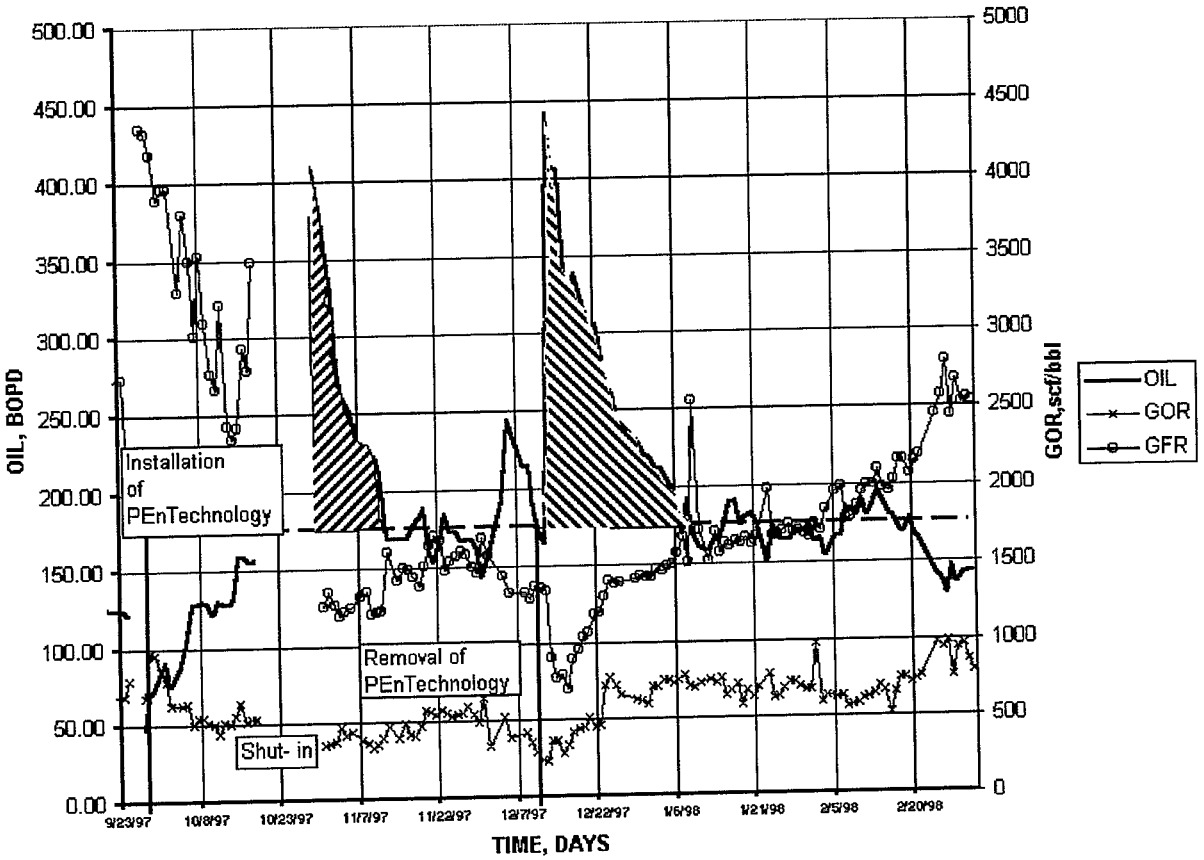


Fig. 3 - Well performance from October, 1997 through March, 1998.

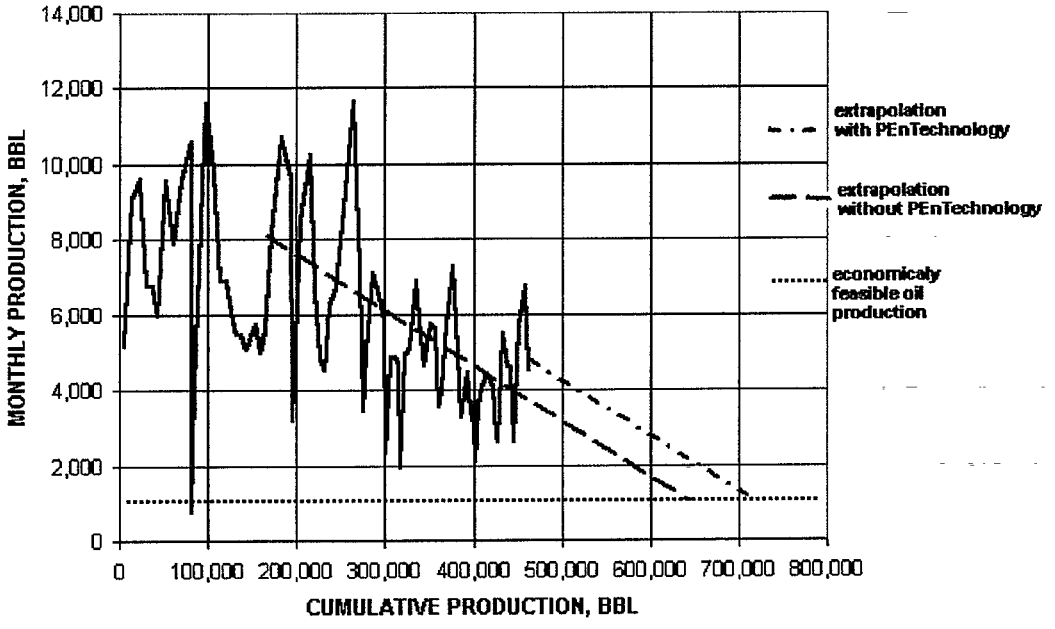


Fig4. Monthly oil production versus cumulative oil production.