

GEOL. CROAT.	49/2	299 - 303		1 Tab.		ZAGREB 1996
--------------	------	-----------	--	--------	--	-------------

Professional paper

Some Experience with Drilling and Use of Horizontal Wells and Way of Their Application in Croatian Hydrocarbon Reservoirs

Ivo STEINER¹ and Boris BURGER²



Key words: Horizontal wells, Geological structures, BHA, MWD, LWD, Well completion.

Ključne riječi: vodoravne bušotine, geološke strukture, sklop alatki na dnu bušotine, telemetrija, geometrija, opremanje bušotina.

Abstract

In many hydrocarbon reservoirs horizontal well paths enable the more economical extraction of oil and gas than with vertical wells in the same reservoirs. This is especially true for cases of by-passed oil in partially depleted reservoirs. Successful design and drilling of horizontal wells is made possible by detailed knowledge of the geological structure, together with up-to-date geophysical and other data. The drilling and production of the first horizontal well in Croatia are discussed and analysed. Methods for drilling and completion of horizontal wells, together with a proposal for their global utilization, are presented.

Sažetak

Vodoravni kanali bušotina omogućavaju u mnogim ležištima ekonomičniji dohvat nafte i plina od uspravnih bušotina, a osobito dohvat zaostale nafte u djelomično iscrpljenim ležištima. Dobro poznavanje geološke grade, dopunjeno svrhovitom primjenom suvremenih geofizičkih i ostalih dostignuća, omogućava uspješno projektiranje i izvedbu vodoravnih bušotina. Razmatraju se iskustva izrade i uporabe prve vodoravne bušotine u Hrvatskoj, te se, usporedbom sa svjetskim iskustvima, predlažu načini izrade daljnjih takvih bušotina, njihovo opremanje i uporaba.

1. INTRODUCTION

Recent technology facilitating the direction control of the borehole path enables the positioning of a well from any starting point on the surface (or subsurface) to any desired point in the subsurface providing it is within the technical capabilities of the available drilling rig and drill tools (STEINER & BOŠKOV STEINER, 1994). Such wells consist of:

- a vertical section;
- a build-up (curved) section, and
- a horizontal or extended-reach section.

The drilling of horizontal wells, i.e. those wells the final part of whose has a horizontal path, has become a routine operation for which the following are prerequisites:

- a) a good knowledge of the geological structure of the drilled area, particularly of the target layer, its overlaying and underlying strata (SOLOMON et al., 1994; WEST & BODNAR, 1994);
- b) to have a corresponding bottom hole assembly (BHA) at disposal (AGAVANI et al., 1994; RAFIE et al., 1986);

- c) to have corresponding measurement while drilling (MWD), and logging while drilling (LWD) equipment at disposal (ANON., 1993; TANGUY & ZOELLER, 1981; HANSEN & WHITE, 1991);
- d) to have a well equipped drilling rig (if possible, with a top drive, a circulating elevator, etc.) for smooth drilling of the curved and horizontal part of the well (STEINER & BOŠKOV STEINER, 1994);
- e) to have a well designed and well equipped system for drilling fluid circulation and control (a linear shale shaker, centrifuges, etc.) and an adequate drilling fluid, as e.g. a polymer drilling fluid. Polymer fluids have good rheological properties, they thoroughly clean the borehole channel of rock cuttings, and they prevent settling of those cuttings. These fluids form a thin, tough filter cake on borehole walls which protects the productive zone from infiltration of the drilling fluid. This cake has a good lubricating property and can be removed easily by a later realized fluid depression on the permeable and porous strata (STEINER & BOŠKOV STEINER, 1994).

Naturally, selection of an adequate drilling fluid, pumping rates, control of torque and drag of the drill string and casing, blowout prevention and other factors affect the safe and effective drilling and these should not be neglected.

The adequate completion of drilled horizontal wells is even more complex (AUSTIN et al., 1988; LESSI & SPREUX, 1988). Long-term and adequately high production of hydrocarbon fluids (oil and/or gas) from a

¹ Faculty of Mining, Geology and Petroleum Engineering of the University of Zagreb, Pierottijeva 6, HR-10000 Zagreb, Croatia.

² INA-Naftaplin, Šubićeva 29, HR-10000 Zagreb, Croatia.

horizontally drilled reservoir can be ensured by the right choice and qualitative realization of well completion. This is especially true in the case where some by-passed oil or gas are targets (MOHAMAD & SNIJDER, 1986).

The most inexpensive and in some cases sufficiently productive methods of completion are an open hole, and landing a slotted uncemented liner (as in the Okoli horizontal well). However in heterogeneous layers, as is the case for most of the targets in Croatia, such solutions may cause undesired mixing of oil, gas and/or water (KRILOV et al., 1996). Such mixing may minimize or even cause cessation of the expected fluid production. Sophisticated and relatively inexpensive completion methods of horizontal wells are available, and these may eliminate such problems (DUDA & YOST, 1995; BRADICK, 1993).

Primarily, horizontal and ER (extended reach = nearly horizontal) wells are drilled in reservoirs having:

- low permeability and/or
- problems with water or gas coning and/or
- low thickness of the pay zone and/or
- secondary permeability (fractures or fissures).

2. PREREQUISITE GEOLOGICAL DATA

Before producing a design for a horizontal well and defining its radius of curvature, build-up rate, kick-off point, placement of tangent(s), etc. it is necessary to consolidate all the available data from vertical or deviated wells in the region of the planned well. Geologists and geophysicists familiar with the area should be included into the team which is preparing and controlling the drilling and completion of a horizontal well. All available data on the geological structure and geophysical surface measurement of the location have to be studied and any missing measurements (such as 3D seismic etc.) have to be obtained and analysed (SKOPEC, 1993; LAMUS PARA, 1992). In the case of the Okoli horizontal well the analysis was not based on a 3D seismic survey, but only on a 2D seismic study, together with detailed knowledge of the Okoli field and past experience of similar scenarios. In addition to extensive knowledge of the expected geological facies it is important to know the rock stability and existing vertical restrictions inside the target reservoir. There are technical restrictions in obtaining large rock cuttings and core from the horizontal part of the well. Therefore cuttings and cores from nearby vertical or less deviated wells have to be used for analyses (KRILOV et al., 1996).

A lot of valuable data can be obtained in real-time by LWD measurement, before serious formation damage has begun. Comparison of these data with data obtained after the drilling is completed can give indications concerning the effective stimulation of future fluid production (LAYNE & YOST, 1994).

3. BOTTOM HOLE ASSEMBLY

A number of particular tools used for BHA (bottom hole assembly) exists, designed for deviated and/or for straight sections of horizontal wells. These are subs. stabilizers, PDM (positive displacement motors), non-magnetic drill collars, flexible drill pipes, etc. For those operators who drill only a few horizontal wells the best solution is to rent a service from one of the service companies specializing in horizontal drilling or to rent only the necessary parts of an adequate BHA from them. In this example a medium radius build-up rate of 3°/10 m having a radius of 250 m and a lateral deviation of 290 m were chosen. For such a job an accustomed drill string may be used without flexible drill pipe and other sophisticated tools. Computer models aiding the optimal choice of the BHA exist (BIRADES, 1986; KIKUCHI, 1993).

Recently, horizontal wells are often drilled with rigs having coiled-tubing as a part of the drill string (WU & JUVKAM-WOLD, 1993; EDGE et al., 1994). Even though voluminous and expensive equipment is necessary for drilling with coiled-tubing, it has the distinct advantage of shortening the time for round-trips which decreases the cost of horizontal drilling. Coiled-tubing and handling equipment can be rented at a reasonable price from companies producing them.

4. MWD AND LWD

In order to correctly drill a horizontal well it is essential to have data on the azimuth and dip angle of the well path. Collection of such data in real-time enables the necessary corrections to be made by changing weight on the bit, bit rotation, bit face position etc. If data is obtained by mud pulses, which is the most widely used method, the necessary corrections on the hole bottom are limited, since there is only a one-way communication from the BHA toward the surface. In the application of mud pulsing signals there is a need for a homogenous, continuous fluid column in the drill string through which pulses are transported.

If underbalanced drilling, with aerated drilling fluid or air drilling is applied, mud pulses cannot be transported from the BHA to the surface. In the case of infill wells toward by-passed oil and/or gas, it is often advisable to apply underbalanced drilling. Signals from the BHA can be transported by electromagnetic waves where the circuit is formed from the transmitter at the BHA through drilled rocks to the receiver on the surface and backward through the drill string. Signals can be sent in two directions, one carrying data from the BHA and the other carrying commands from the surface allowing change to the parameters at the BHA.

Electromagnetic MWD/LWD has to be taken seriously as a convenient alternative in horizontal drilling for by-passed oil and/or gas and in drilling of re-entries in reservoirs with depleted pressure.

Diameter (mm)	Diameter (inch)	Planned (m)	Realized (m)	Remark
508.0	20	100	111	
339.7	13 3/8	1800	1898	covered SGS*
244.5	9 5/8	2360	2311	many differ. stuck - pipe
177.8	7	2350-2860	2280-2442	stuck-liner
177.8	7	-	2243-2268	
137	5	-	2268-2892	

Table 1 Planned and realized casing program - Okoli horizontal well. * SGS = subsurface gas storage.

5. COMPLETION

If there is any reason for avoiding simple solutions such as an open hole completion or landing of a slotted liner without packing, such as heterogeneous layers with variable oil, water and gas saturation, various permeability, pressure differences in drilled rocks in the horizontal part of the well, loose sand etc. it is advisable to apply designs with inflatable packers, partial cementing, gravel packing and/or with slotted liner having sliding ports. For more effective drainage of a drilled reservoir a multi-branch completion may be an effective solution (STEINER & BOŠKOV-STEINER, 1994).

As the purchase and landing of liners with existing sophisticated completion methods is a very expensive and complex venture, it should be thoroughly analysed whether the invested amount of money can be covered by the value of increased production.

6. OKOLI WELL - THE FIRST HORIZONTAL WELL IN CROATIA

The Okoli field is a gas and gas condensate producing field situated in the Sava trench, the most Southern part of the Pannonian basin. In Tertiary sediments there are three productive reservoir-series: A, B and C.

The A-series is closest to the surface. It was depleted until a pressure gradient of .44 bar/10 m was reached. It is now serving as a subsurface gas store (SGS). When it is filled with stored gas the pressure gradient is elevated to .94 bar/10 m. When the vertical part of the horizontal well was drilled through this series the pressure gradient was at the highest level.

The B-series is in production and its pressure gradient varies between .31-.33 bar/10 m.

The C-series reservoir, which was the target of the horizontal well, is an anticline consisting of a number of thin, sandstone deposits characterised by low-permeability and interlayered with non-permeable shale. The horizontal well path is situated on the top of the anticline with its lateral part following the crest of the elongated anticline. The pressure gradient in the C-series varies between .45-.90 bar/10 m.

The aim of the first horizontal well in Croatia was to increase gas production from a low permeability, thin

layer reservoir (so called sandwich structure) and to prove whether a horizontal well is able to produce at least 1.5 times the volume of gas per day than that of a vertical well stimulated by hydraulic fracturing in the same reservoir. Therefore a thorough study was undertaken with a calculated four year period for return of the investment.

Taking into consideration the available tools, equipment and financial resource, the INA-Naftaplin company decided to drill a horizontal well into the Okoli gas bearing C-series from a kick-off-point at 1,925 m. It was planned to case the lateral section (of about 500 m) with a slotted liner of 7 inch diameter and to cover non-stable reservoir rock with that liner. The Okoli horizontal well casing program is shown in Table 1.

Realization of the curved and horizontal part of this first horizontal well in Croatia was entrusted to an experienced international service company. The aim was to include a partner able to offer an integrated service which would help in drilling, well completion and commissioning of the horizontal well.

Due to low pressure gradients the underbalanced drilling method was considered. However operating company did not have the necessary equipment. Renting of such equipment and expense of purchasing necessary material meant that the expected financial result from well production would be lower than the financial investment required and this method was therefore abandoned.

The gas reservoir of the B-series is located in the build-up section of the well. Since the pressure gradient in this series is low (.31-.33 bar/10 m) and the polymer drilling fluid had a density of 1,050 kg/m³, it was expected to get stuck pipe due to differential pressure. But since the filter cake was fatty and slippery this was expected to be mitigated. However due to frequent sticking pipe it was decided to switch from a sliding mode to rotary mode, which caused the build-up rate (BUR) to be lost. Drilling was stopped and it was decided to continue with a smaller bit diameter and with a more flexible drill string, in order to retrieve back the desired BUR. At a depth of 2,311 m a 9 5/8 inch diameter casing string was landed and cemented.

When the final length of the hole at 2,900 m was achieved, an attempt had been made to land a slotted liner of 7 inch diameter. This liner was equipped with a wash pipe in case the liner became stuck so that, by cir-

ulation and by applying the driller's method, the liner may be freed. The slotted liner was also equipped with spiral, rigid blade centralizers. During running of the liner it became stuck when its casing shoe was at 2,472 m (161 m beyond the previous casing). The wash pipe failed. A top drive, a power swivel and/or circulating elevator were not available. By pulling it, the liner was made free, and when pulled for about one pipe stand, at a length of 2,442 m it became stuck again (a centralizer stuck in the shoe of the 9 5/8 inch casing string). This problem was solved by cutting the 7 inch liner at 2,280 m, 31 m above the shoe of the 9 5/8 inch diameter casing. The free part of the 7 inch liner was pulled out of the hole. After drilling through the bottom assembly of the 7 inch pipe the hole was completely cleaned, following which a 5 inch slotted liner with a wash pipe at the shoe and no centralizers, was run to the well bottom. A liner hanger, prepared for the 7 inch liner, was adapted with a 7x5 inch joint and was used for fixing the 5 inch liner to the previous casing string.

The well was finished according to the designed trajectory and generally completed according to the designed casing program, with exception of the substitution of a 5 inch liner instead of the designed 7 inch one. It was accomplished according to the predicted time schedule, except of an additional ten days spent for fishing job.

According to laboratory tests with core from a similar reservoir (KRILOV et al., 1996) it is estimated that a formation damage of 33% of the original permeability exists, caused by the applied polymer drilling fluid and a synthetic formation water. This test may be repeated since core exists from the same reservoir and formation water from it may be collected.

Production equipment with a permanent packer and a 3 1/2-inch tubing was run and satisfactory gas production has been achieved. The horizontal well has attained following production:

- a) 500% higher production than that of an average vertical, unstimulated well from the same reservoir;
- b) 180% higher production than that from a vertical well in the same reservoir which was stimulated by hydraulic fracturing.

Purchase of equipment and tools needed for the lateral interval of the well required approximately 6% of the total cost of the well. Service costs (special tools and equipment, MWD and their handling) have amounted to about 8% of the total drilling costs. For various materials 45% of that cost was needed and 55% was paid to the service company. The horizontal well was in total 44% more expensive than an average vertical well of the same length. The cost per meter of the drilled horizontal well was approximately 900 USD.

In the horizontal part of the borehole no classical well logging was done as it were not needed and the equipment and tools required such as carriers and joints with side door opening for entrance of the cable were unavailable.

Workover in the horizontal part of the well could not be performed either as there were no adequate coiled tubing and necessary tools available. Application of ECP-s (external casing packers) was not planned because they are too expensive in comparison with calculated value of producible gas and because the equipment for activating such packers was unavailable. Consequently, no stimulation job can be performed in this borehole because no section surrounding the borehole can be isolated.

7. CONCLUSIONS

Globally the application of horizontal wells for increasing the hydrocarbon fluid production from otherwise inaccessible or poorly accessible reservoirs has become an everyday practice in the world, and thousands of such wells are drilled annually. In the search for by-passed oil and/or gas and for their production horizontal wells are the most effective means. In Croatia we can expect a reasonable quantity of by-passed oil and/or gas in a number of previously discovered and non-rationally depleted reservoirs as well as in the vicinity of more recently discovered ones. There is a need to study each of the existing reservoirs and establish whether horizontal wells would help finding existing by-passed oil and/or gas and increasing the oil and gas production.

Without a decision to drill significantly more horizontal wells in a short period there is no reason to purchase or produce special equipment and tools for horizontal and/or ER-drilling. It is more reasonable to hire specialized service companies with good references who are able to offer a reasonable price of service in fair competition.

Acknowledgment

This paper is based on work sponsored by the Croatian-American Joint Fund in cooperation with the US Department of Energy under project JF No. 278.

8. REFERENCES

- AGAVANI, M., RAHMAN, S.S. & MAIDLA, E.E. (1994): A new approach to selecting optimum bottom hole assembly configuration for any given well trajectory.- SPE Asia Pacific Oil and Gas Conference, SPE paper 28774, 9 p., Melbourne.
- ANON. (1993): State of the art in MWD.- 2nd Edit., Intl' MWD Society, Houston, 32 p.
- AUSTIN, C., ZIMMERMAN, C., SULLAWAY, B. & SABINS, F. (1988): Fundamentals of horizontal well completion.- Drilling, May-June, 28-31.
- BIRADES, M. (1986): ORPHEE 3D: Static and dynamic threedimensional BHA computer models.- 61th

- Annual Tech. Conf. and Exhib. of the SPE, SPE paper 15466, New Orleans, 12 p.
- BRADICK, B. (1993): Vizszintes kutkikepzési módszerek.- *Koccolaj es foeldgaz*, 25(125)/7, 207-210.
- DUDA, J.R. & YOST, A.B. (1995): DOE/Fossil energy's drilling, completion and stimulation R&D: A Technologies/Products Overview.- SPE Eastern Regional Conf. and Exhib., SPE paper 30993, Morgantown, 16 p.
- EDGE, E., BRINKHORST, J., VOELKER, H., BURGE, P. & EVEN, R.L. (1994): Further advances in coiled-tubing drilling.- EUROPEC, SPE paper 28866, London, 9 p.
- HANSEN, R.R. & WHITE, J. (1991): Features in logging-while-drilling (LWD) in horizontal wells.- SPE/IADC Drilling Conference, SPE paper 21989, Amsterdam, 9 p.
- KIKUCHI, S. (1993): 2D & 3D planning for horizontal wells.- SPE Middle East Oil Tech. Conf. and Exhib., Bahrain, SPE paper 25647, 15 p.
- KRILOV, Z., WOJTANOWICZ, A.K. & TOMIC, M. (1996): Formation damage in horizontal wells caused by polymer mud.- SPE Formation Damage Symposium, SPE paper 31135, Lafayette, 16 p.
- LAMUS PARA, A.U. (1992): Operational geological experiences of horizontal wells.- Second Latin American Petrol. Eng. Conf. (II LAPEC) of the SPE, SPE paper 23654, Caracas, 11 p.
- LAYNE, A.W. & YOST, A.B. (1994): Development of advanced drilling, completion and stimulation systems for minimum formation damage and improved efficiency: A Program Overview.- SPE Intl' Symp. on Form. Dam., SPE paper 27353, Lafayette, 7 p.
- LESSI, J. & SPREUX, A. (1988): Completion of horizontal drainholes.- SPE Meeting on Petrol. Eng., SPE paper 17572, Tianjin, 10 p.
- MOHAMAD, A.Y. & SNIJDER, G.L. (1986): Identification of bypassed oil using Gamma-Ray spectrometry tool in old wells.- SPE Offshore South East Conf. and Exhib., SPE paper 14604, Singapore, 10 p.
- RAFIE, S., HO, H.-S. & CHANDRE, U. (1986): Application of a BHA analysis program in direction drilling.- SPE/IADC Drilling Conference, SPE paper 14765, Dallas, 10 p.
- SKOPEC, R.A. (1993): Characterization in reservoirs targeted for horizontal drilling.- *Jour. Pet. Tech.*, 1168-1176, SPE paper 22709.
- SOLOMON, S.T., ROSS, K.C., BURTON, R.C. & WELBORN, J.E. (1994): Multidisciplined approach to designing targets for horizontal wells.- *Jour. Pet. Tech.*, 143-149, SPE paper 25506.
- STEINER, I. & BOŠKOV STEINER, Z. (1994): Tehnologija vodoravnoga bušenja.- *Barbat*, Zagreb, 170 p.
- TANGUY, D.R. & ZOELLER, W.A. (1981): Applications of measurement while drilling.- 56th Annual Fall Techn. Conf. and Exhib. of the SPE, SPE paper 10324, San Antonio, 16 p.
- WEST, C.C. & BODNAR, D.A. (1994): Review of the geological environment for horizontal wells.- Second Archie Colloquium, SPE paper 23544, Houston, 10 p.
- WU, J. & JUVKAM-WOLD, H.C. (1993): Drilling and completing horizontal wells with coiled tubing.- 68th Annual Tech. Conf. and Exhib., SPE paper 26336, Houston, 17 p.

