Horizontal UBO can outperform conventional wells

UNDERSTANDING THE MAGNITUDE and the driving factors behind the success and failure of UBD projects is critical to the growth and acceptance of the technology. Horizontal techniques excel in reservoirs that are naturally fractured or highly heterogeneous or that exhibit gas or water coning problems. Horizontal wells can also benefit low-permeability reservoirs by draining a larger area per well, thus reducing the number of wells needed to drain the reservoir.

The development of horizontal UBD, in its current form, began in the early 1990s. Significant development has taken place in the areas of equipment design, operational techniques and the understanding of what occurs in the reservoir during underbalanced operations.

One considerable shortcoming, however, is the distinct lack of published literature that clearly demonstrates that horizontal UBD is an economically effective field development method compared to conventional drilling, completion and stimulation techniques.

The majority of industry knowledge on horizontal UBD is based on anecdotal evidence, in-house analyses not available to the public, and case histories focused on operational aspects or very early time production results. Published literature that examines the long-term performance of previous UBD programs is virtually non-existent.

A number of underbalanced campaigns in the Western Canadian Sedimentary Basin have several years of production data. An analysis of these case studies demonstrates that horizontal UBD is a viable field development technique and quantifies the significant economic benefit that can be achieved. The analysis also includes programs in which UBD was not successful and investigates the reasons for failure.

METHODOLOGY

Determination of the overall economic performance of both conventional and underbalanced techniques requires a production forecast to extrapolate existing production data to abandonment.

All analyses were based on production data only because flowing pressures were unavailable. Therefore, Arps' decline curve analysis was chosen as the forecasting method.

Arps' decline analysis is only valid during boundary-dominated flow, so a test was required for determining whether this is true for all of the wells analyzed. Fetkovich-type curves provide the diagnostic functionality for confirming that boundary-dominated flow exists, confirming that Arps' decline analysis is valid, and determining the appropriate curves ("b" exponent) with which to forecast.

Thus, Fetkovich-type curves were used to confirm that all the wells examined in this analysis were in boundary-dominated flow. Then the forecast was generated using Arps' methods.

After production forecasts were generated, discounted cashflow analysis was performed to generate economic indicators for the comparison of conventional and underbalanced techniques, such as net present value (NPV) and internal rate of return (IRR). For simplicity, all comparisons were based on cash flows before taxes and royalties.

CASE STUDIES-POSITIVE

The following case studies present the results of campaigns in which horizontal underbalanced wells outperformed the offsetting conventional producers.

Elkton Formation-Harmattan East Field. The Elkton formation is the productive member of the Rundle group in the Harmattan East field, located in Central Alberta (Twp 33 Rge 3 W5M). The formation is an Upper Mississippian-age dolomitized carbonate. Key general reservoir properties are as follows:

Depth	~2,450 m
Permeability	0.1 to 5.0 mD
Porosity	6 to 12%
Initial water saturation	11 to 30%
Gross pay	8.7 to 32.8 m
Initial pressure	12.3 to 21.6 MPa

This field first began producing in 1967, with a number of petroleum companies involved in its early development. Initial exploitation of the field entailed the vertical drilling of wells overbalanced and subsequent hydraulic fracturing of the Elkton to optimize production. In the early 1990s, operators began to apply a combination of 3-D seismic activity, complemented by overbalanced horizontal drilling to maximize production from the Elkton.

However, **Apache Canada Ltd** found that "overbalanced horizontal well applications indicated moderate if any improvements over vertical wells" and that "subsequent stimulation attempts of damaged horizontal wells have proven to be ineffective".

Therefore, Apache believed that the application of UBD might be a better technology choice for this reservoir. Apache drilled its first underbalanced well in this reservoir in 1996 and was soon followed by other operators in the area.

The horizontal underbalanced wells increased initial production by an average of 24% and are projected to recover approximately 32% more gas in a 10 year period.

Economic analyses were performed on the production forecasts. Table 1 illustrates the average results on the underbalanced and conventional cases.

Table 1. Elkton Formation Analysis Average Results

	Conventional	Underbalanced
Well Cost	$2,500,000	$2,500,000
EUR(106m3)	176.2	226.7
NPV	$12,870,982	$18,033,106
IRR	127%	206%
Payout Period	16.1 months	9.4 months

Although well costs were similar between the stimulated horizontal wells and the underbalanced horizontal wells, the underbalanced wells are predicted to recover approximately 29% more gas per well and realize a 40% improvement in NPV. The underbalanced wells also are expected to improve IRR by 62% and reduce the payout period by 42%.

Glauconitic Formation-Garden Plains Field. The Garden Plains field is situated in southeastern Alberta (Twps 33-34 Rges 11-12 W4M). The Glauconitic formation in this field is a lower-Cretaceous sandstone consisting of incised valleys filled with lithic, fluvial deposits.

Typically, the Glauconitic was vertically drilled and hydraulically fractured. In 1999 and 2000, a junior independent Canadian oil and gas operator conducted a five-well UBD program in this field over a 5 X 16 km area. Key general reservoir properties are as follows:

Depth	1,280 m
Permeability	0.1 to 1.2 mD
Porosity	12 to 27%
Initial water saturation	32 to 64%
Net thickness	1.7 to 23.5m
Initial pressure	5.4 to 8.7 MPa

The horizontal underbalanced wells increased initial production by an average of 118%. The underbalanced horizontals are projected to recover approximately 43% more gas in a 10-yr period.

Economic analyses were performed on the production forecasts. Table 2 presents the average results on the underbalanced and conventional cases.

Table 2. Glauconitic Formation Analysis Average Results

	Conventional	Underbalanced
Well Cost	$755,000	$950,000
EUR (100 m')	22.5	25:0
NPV	$1,862,763	$2,821,906
IRR	117%	250%
Payout Period	11.7 months	9.25 months

The underbalanced wells are predicted to improve recovery per well by 11%. Although the underbalanced wells increased the average well cost by 26%, the NPV and IRR were increased by 52% and 113%, respectively, and the payout period was reduced by 21%.

Pekisko Formation— Three Hills Creek Field. The Pekisko is an early Carboniferous, clean limestone formation, prevalent throughout much of Alberta. In the Three Hills Creek field, it is coarsely crinoidal and fragmental to fine-grained, sparsely crinoidal.

Typical Pekisko development was through vertically drilled wells, which were stimulated by acidizing, hydraulic fracturing

Depth	1,740 m
Permeability	0.25 to 5 mD
Porosity	4.5 to 11 %
Initial water saturation	20 to 30%
Net thickness	1.7to 10.3m
Initial pressure	3 -to 12 MPa

or acid fracturing. A seven-well horizontal underbalanced program was undertaken in 1997.

The horizontal underbalanced wells increased initial production by an average of 238%. The underbalanced horizontals are projected to recover approximately 138% more gas in a 10-yr period.

Economic analyses were performed on the production forecasts. Table 3 presents the average results on the underbalanced and conventional cases.

Table 3. Pekisko Formation Analysis Average Results

	Conventional	Underbalanced
Well Cost	$950,000	$1,500,000
EUR(106m3)	43.5	112.9
NPV	$3,769,884	$10,056,993
IRR	121%	313%
Payout Period	13.9 months	9.6 months

Gething X Pool-Kaybob Field. The Gething in the Kaybob area is a highly heterogeneous, fluvial-incised valley fill deposit. The lithology consists of conglomeratic, coarse to fine-grained facies. A UBD program was undertaken around the Kaybob field in 1998 and 1999, in two separate, nearby pools. Results of this program varied dramatically between the two pools. In the Gething X pool, the program was successful, but in the Chickadee Gething D pool, it was not. This case study examines the successful case; the unsuccessful case is discussed later. Key general reservoir properties are as follows:

Depth	~1,845 m
Permeability	0.07 to 4.2 mD
Porosity	10.5 to 19.7%
Initial water saturation	23 to 47%
Net thickness	1.9 to 11.5 m
Initial pressure	11.9 to 15.0 1 MPa

The horizontal underbalanced wells increased initial production by an average of 254%. The underbalanced horizontals are projected to recover approximately 121% more gas in a 10-yr period.

Economic analyses were performed on the production forecasts. Table 4 presents the average results on the underbalanced and conventional cases.

Table 4. Gething Formation Analysis Average Results

	Conventional	Underbalanced
Well Cost	$1,371,000	$1,930,000
EUR(106 m3)	31.6	60.2
NPV	$2,407,730	$6,558,720
IRR	129%	170%
Payout Period	28.2 months	5.5 months

CASE STUDIES-NEGATIVE

For UBD to be successful, appropriate operational techniques must be applied in suitable candidate reservoirs. The following case studies illustrate programs in which either the reservoir was not an appropriate candidate for horizontal underbalanced wells, or the operational techniques employed led to formation damage, thus sacrificing the economic viability of the technique.

Cardium Formation-Ansell Field. The Ansell field is located in the Foothills region of Central Alberta (Twps 50- 53, Rges 19-20 W5M). A major underbalanced horizontal drilling campaign was implemented primarily during the winters of 2000 and 2001.

The target formation was the Cardium zone, a Cretaceous-age, fine-grained marine sandstone. Key reservoir properties are as follows:

Depth	~2,250 m
Permeability	0.05 to 1.7 mD
Porosity	9.5 to 13%
Initial water saturation	17 to 37%
Net thickness	5 to 19 m
Initial pressure	15.4 to 21.9 MPa

Horizontal lengths ranged from 20 to 985 m, averaging approximately 500 m. The shorter horizontal lengths were the result of either hole problems (i.e., stuck drillstring) or equipment problems (both downhole and at surface). Some of these problems necessitated sidetracking of some of the wells. Liquid injection rates were low on some of the wells and it is surmised that hole cleaning may have been less than efficient, thereby resulting in stuck pipe situations. Wiper trips were often conducted to condition the hole.

Initial production from the vertical wells was 27% higher than for the underbalanced horizontals. The vertical wells are projected to recover approximately 37% more gas in a 10-yr period.

Economic analyses were performed on the production forecasts. Table 5 presents the average results on the underbalanced and conventional cases.

Table 5. Cardium Formation Analysis Average Results

	Conventional	Underbalanced
Well Cost	$1,900,000	$2,675,000
EUR (106 m’)	66.3	46.8
NPV	$6,170,600	$3,474,400
IRR	173%	71%
Payout Period	14.7 months	24.2 months

As the results of the analysis indicate, the conventional wells are better performers than the horizontal underbalanced wells. The apparent reasons are that (a) the Cardium in the Ansell region is not an appropriate candidate for horizontal UBD, and (b) the as-drilled horizontal well design was not competitive with hydraulic fracturing in the first place. There is also evidence that the UBD operations were not optimally designed to minimize formation damage.

In terms of candidacy, the Cardium appears, based on its properties, to be a better candidate for hydraulic fracturing than for horizontal underbalanced wells. The in-situ permeability is very low, low enough, in most cases, to make horizontal wells not very economically viable. Although natural fracturing does occur, it is not prevalent enough to increase the effective permeability to a level at which horizontal wells would be effective.

In addition, the well design did not help the economic performance of the wells. Using the concept of effective wellbore radius, the as-drilled net effective horizontal length was not sufficient to create an effective wellbore radius greater than the average radius created by hydraulic fracturing.

From the outset, the wells were not designed to be more productive than the vertical wells. Thus, the extra expense to drill the horizontal wells was not offset by the difference in production.

The underbalanced wells do outperform the conventionally drilled wells, giving good evidence that the underbalanced wells were effective in reducing formation damage to some extent. Based on the factors stated above, however, the underbalanced wells are not economically effective in comparison to the offsetting vertical, hydraulically fractured wells.

Gething D Pool-Chickadee Field. Unlike the wells in the Kaybob Gething X pool, the wells drilled in the Chickadee Gething D pool were not successful in comparison to the conventionally drilled and stimulated wells. Two wells were drilled in this pool, but only one was produced. Key general reservoir properties are as follows:

Depth	~1,845 m
Permeability	0.09 to 1.9 mD
Porosity	12 to 16.7%
Initial water saturation	29 to 50%
Net thickness	3.1 to 14.2m
Initial pressure	9.8 to 14.9 MFa

Initial production from the vertical wells was 44% higher than for the underbalanced horizontals. The vertical wells are projected to recover approximately 22% more gas in a 10 year period.

This projection is based on the one producing well. The fact that the other horizontal underbalanced well was abandoned should also be considered when comparing the performance of the two techniques.

Economic analyses were performed on the production forecasts. Table 6 presents the average results on the underbalanced and conventional cases.

Table 6. Gething Formation Analysis Average Results

	Conventional	Underbalanced
Well Cost	$1,371,000	$1,940,000
EUR(106m3)	59.7	45.7
NPV	$4,464,040	$2,937,340
IRR	85%	48%
Payout Period	16.1 months	24 months

Based on the reservoir properties, it would be expected that the wells drilled in the two different Gething pools would be similar in performance. Analyzing the UBD operational data, however, reveals that the operational techniques used in the program had a negative effect on ultimate productivity.

Poor bottomhole pressure, transient management and inefficient hole cleaning yielded several instances of the bottomhole pressure exceeding the pore pressure adjacent to the well bore.

From this data, it can be assumed that the reservoir had been damaged during the drilling operation.

CONCLUSIONS

Horizontal UBD is a proven technology that can yield significantly greater economic value than conventional drilling operations in selected mature field development scenarios.

Proper candidate selection is of paramount importance when considering application of UBD for field development. UBD is not applicable to all reservoirs. Conventional (overbalanced) techniques can outperform UBD in some reservoirs.

Even if a given reservoir has been selected as a suitable horizontal UBD candidate, appropriate techniques must be used both during drilling and completion operations to achieve the goal of minimal formation damage. If not, sub-optimal production performance and resulting poor economics can occur.

REFERENCE

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