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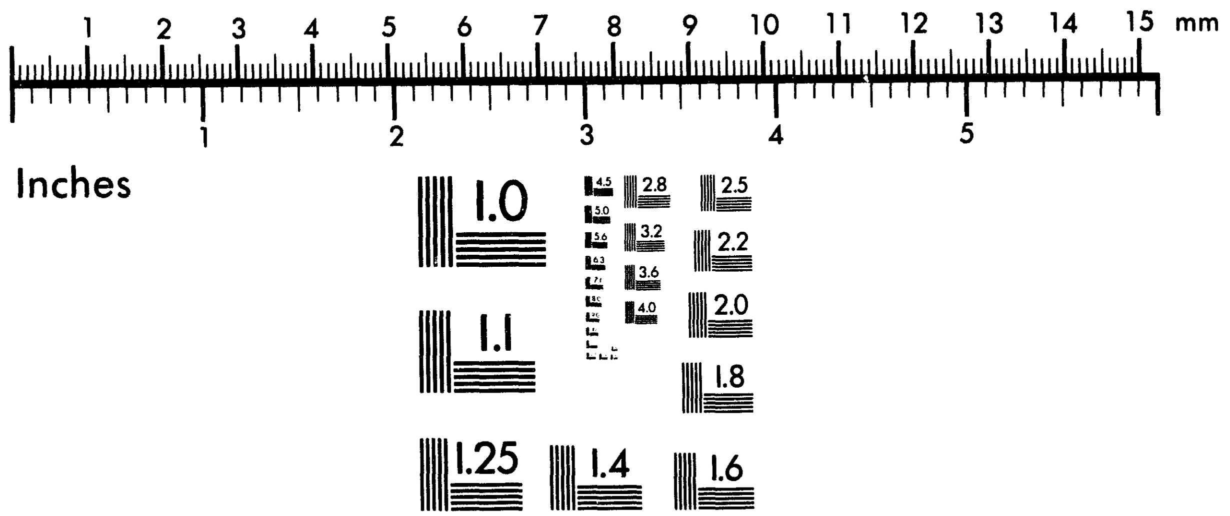

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Technical Progress Report — Draft

Horizontal Oil Well Applications and Oil Recovery Assessment

DOE Contract No.: DE-AC22-93BC14861

Submitted By:
Maurer Engineering Inc.

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Principal Investigator: William J. McDonald
Project Engineer: Greg Deskins
Contracting Officer's Representative: Thomas B. Reid

Report for the Period
April — June 1994

Technical Progress Report — Draft

Objectives

Thousands of horizontal wells are being drilled each year in the U.S.A. and around the world. Horizontal wells have increased oil and gas production rates 3 to 8 times those of vertical wells in many areas and have converted non-economic oil reserves to economic reserves. However, the use of horizontal technology in various formation types and applications has not always yielded anticipated success.

The primary objective of this project is to examine factors affecting technical and economic success of horizontal well applications. The project's goals will be accomplished through six tasks designed to evaluate the technical and economic success of horizontal drilling, highlight current limitations, and outline technical needs to overcome these limitations. Data describing operators' experiences throughout the domestic oil and gas industry will be gathered and organized. Canadian horizontal technology will also be documented with an emphasis on lessons the U.S.A. industry can learn from Canada's experience. MEI databases containing detailed horizontal case histories will also be used. All these data will be categorized and analyzed to assess the status of horizontal well technology and estimate the impact of horizontal wells on present and future domestic oil recovery and reserves.

Summary of Technical Progress

Information Base on Horizontal Wells

A database was constructed from well data describing domestic horizontal wells. Three principal formations are the focus of the majority of U.S.A. activity: the Austin Chalk in Texas, the Bakken Shale in North Dakota, and the Niobrara in Colorado and Wyoming. Results from these fields are well known and a large volume of published results is available. Given the objective of the present study, it was decided to focus the analyses on formations other than these three fractured carbonates. Based on domestic well data, over 670 horizontal wells have been completed in other formations as of May 1994.

About 180 operators drilled these other wells in over 110 formations. Questionnaires covering over 60% of the wells were returned by operators.

Specialized Database for Horizontal Well Forecasting

A database describing formations drilled horizontally was constructed in dBASE IV. Questionnaires were received from several sources including operators listed in the original well data file, participant companies in the DEA-44 Horizontal Well Technology joint-industry project, attendees of the Horizontal Technology Forum held in Calgary during July 1993, and attendees of the Horizontal Technology Forum held in Houston during September 1993.

Over 160 database records have been generated. Several questionnaires have been returned describing formations outside the scope of this study, including Austin Chalk wells and wells outside the U.S.A. These data may be evaluated at a later date.

Economic and Technical Trend Analysis

Multiple analyses have been performed on the database. Overview analyses were designed to determine the types and frequency of the various applications of horizontal technology. The three most common applications for U.S.A. horizontal wells include intersecting fractures (listed for 53% of formations), delaying coning (33%), and favorable economics (35%). Least used applications include avoiding surface restrictions (7%), water drive (9%) and EOR (9%).

Operators were asked whether their horizontal applications in each field were technical and/or economic successes. Of 57 responses, 54 were technically successful, representing an overall 95% success rate. Economic success has not been as widespread as technical success. Of 56 responding formations, 28 were economic successes (50%) and 24 were economically unsuccessful (43%). An additional 4 formations (7%) had mixed economic results, that is, multiple operators in a particular field reported both successful and unsuccessful projects. Carbonate applications have been slightly more technically successful than clastic: 100% versus 91%. Conversely, clastics were reported more economically successful than carbonates: 59% versus 45%, respectively.

Production ratios were used as an additional gauge of technological success. These ratios compare the performance of a typical horizontal well in the field to that of a typical vertical well. The most common range of production ratio was 1-2 times the vertical rates (Figure 1), followed by 3-5. The average value was 3.2. A significant number of formations (21%) reported production ratios of 5 or greater.

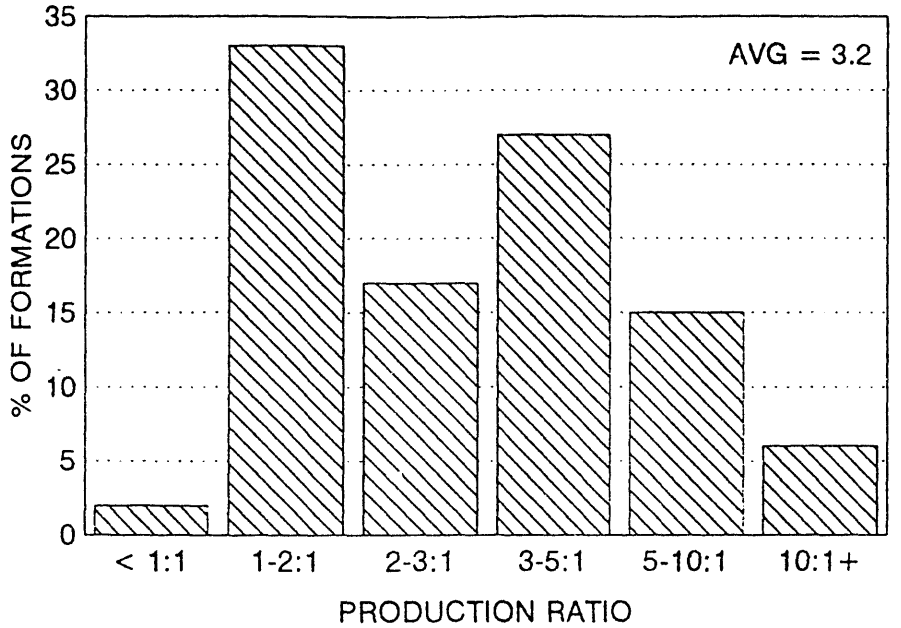

Figure 1. Ratio of Horizontal/Vertical Production for U.S.A. Formations

Cost ratios for all formations range from a low of 0.33 up to 5 times vertical well costs. The average response was 2.0 times the cost of a vertical well. About two-thirds of the responses fell in the range 1.5-3 (Figure 2).

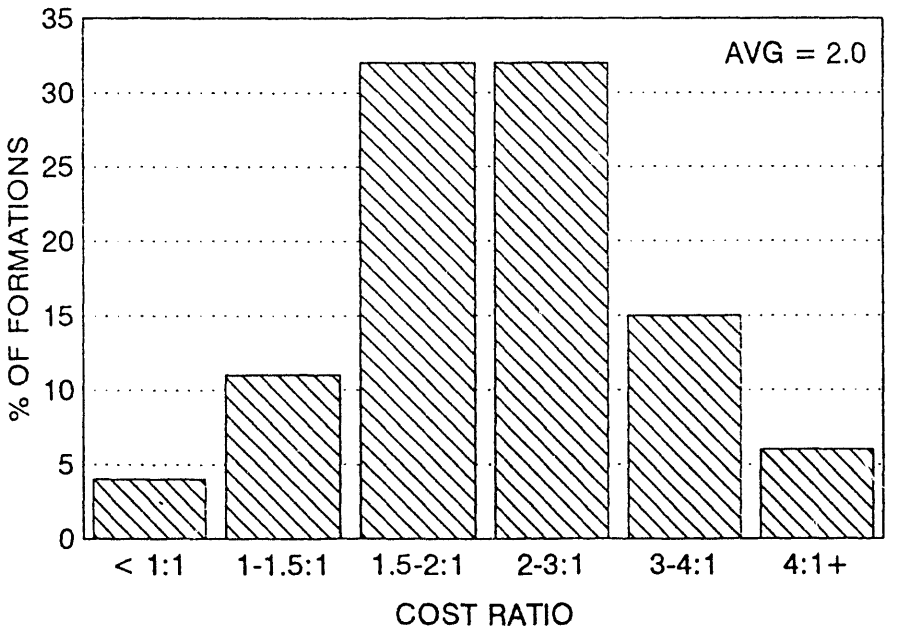

Figure 2. Ratio of Horizontal/Vertical Costs for U.S.A. Formations

The average horizontal application in the U.S.A. produces at a rate 3.2 times greater than a vertical well and costs 2.0 times as much. Thus, according to this simple analysis, the economics of horizontal development have been favorable for the average domestic application.

Horizontal Well Application Forecast

Another key parameter in the project data is the estimated increase in reserves as a result of implementing horizontal technology. Results from 47 questionnaires (Figure 3) show that over half the operators have seen (or predict) an increase of greater than 5%. Horizontal wells are expected to increase recoverable reserves through, for example, delaying the onset of water coning or accessing oil not economically recoverable with vertical wells.

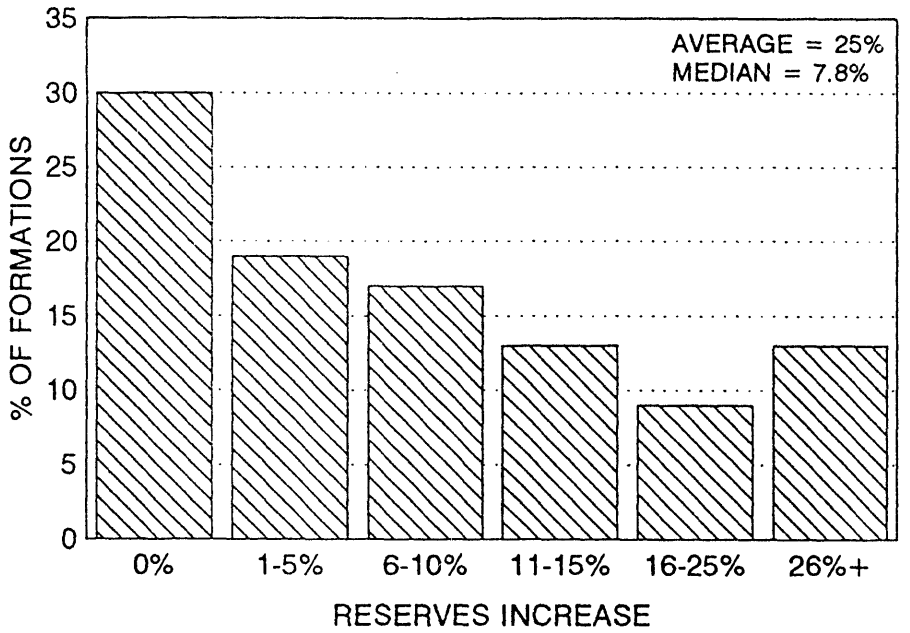

Figure 3. Reserves Increase with U.S.A. Horizontal Wells

Proven U.S.A. oil reserves amount to about 27 billion bbl (TORIS, 1988). This volume represents 5% of the total domestic original oil-in-place (OOIP) of 513 billion bbl. Increases in these reserves due to horizontal development, as reported by survey respondents, ranged from 0% to 300%. The overall average increase is 24.6%. Extrapolated to the total U.S.A. reserves base, this represents an additional 6.6 billion bbl of reserves due to the widespread and appropriate application of horizontal technology.

A second, more conservative reserves increase was derived based on the median reported increase of 7.8%. A domestic reserves increase of this magnitude corresponds to an addition of 2.1 billion bbl. The median might be more representative of the expected impact on reserves in a typical field where a relatively modest impact on reserves is foreseen, e.g., where vertical production rates

are economic. The median value compares favorably with the average increase for formations whose individual increases are less than 100%. Five of 47 reserves increase responses were greater than or equal to 100%. If these data are excluded from the calculation, the average increase in reserves for the U.S.A. is 7.4%.

Average reserves increase for clastic formations is 19.2% (median = 7.9%). Based on total clastic reserves listed in TORIS (18 billion bbl), the average industry-wide increase would represent 3.5 billion bbl. For carbonate reservoirs, the average reserves increase is 34.2% (median = 5.0%). This corresponds to an addition of 2.7 billion bbl to the TORIS carbonate total of 8 billion bbl.

A forecast of the number of horizontal wells to be drilled over the next several years is shown in Figure 4. According to these data, which were obtained from Petroleum Information, API, and Spears and Associates, the number of wells drilled per year has been relatively constant in recent years and will remain at about the same level in the near future.

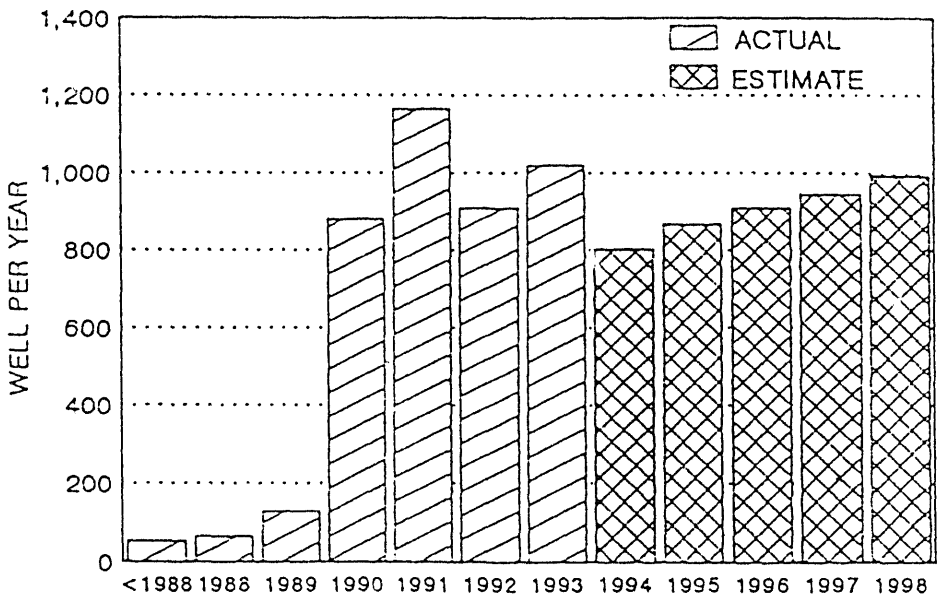

Figure 4. U.S.A. Horizontal Well Forecast

These data also show that 1991 saw the greatest application of horizontal technology, with about 1160 horizontal wells completed. The next most active year was 1993, during which 1020 horizontal wells were completed in U.S.A. fields.

Analysis of Canadian Horizontal Well Experience

Based on analyses of U.S.A. horizontal well data, it became apparent to the project team and DOE that the application of horizontal wells for domestic carbonate reservoirs producing light oil can be adequately documented and analyzed. However, data describing clastic reservoirs producing heavy oil or gas are sparse, and applications of horizontal wells in these formations will be difficult to analyze based on domestic data alone. A major objective of the project is to forecast the future application of horizontal technology in historically less-popular formation types, including clastics.

As a result, the study was expanded to include Canadian horizontal well application data. Canadian operators have exploited a wide variety of formation types with horizontal wells, including unconsolidated sands, fractured carbonates, tight reservoirs, and EOR projects (steam and miscible fluids, and bitumen production).

A listing of Canadian horizontal wells was obtained from Petroleum Information Canada. A total of 1422 wells was cited in four provinces: Saskatchewan (63%), Alberta (34%), British Columbia (3%), and Manitoba (<1%). These wells were drilled by about 140 operators.

Production surveys similar to those distributed to domestic operators were sent to most Canadian operators. Over 110 were returned and analyzed by the project team.

Applications for Canadian horizontal wells are summarized in Figure 5. These include (from left to right): 1) intersect natural fractures, 2) target thin formation, 3) layered or heterogeneous formation(s), 4) water or gas coning, 5) surface restrictions, 6) water drive/water injection, 7) low permeability, 8) gravity drainage, 9) Enhanced Oil Recovery, and 10) favorable economics. Multiple responses were typical; therefore, the results shown in the figure sum to more than 100%.

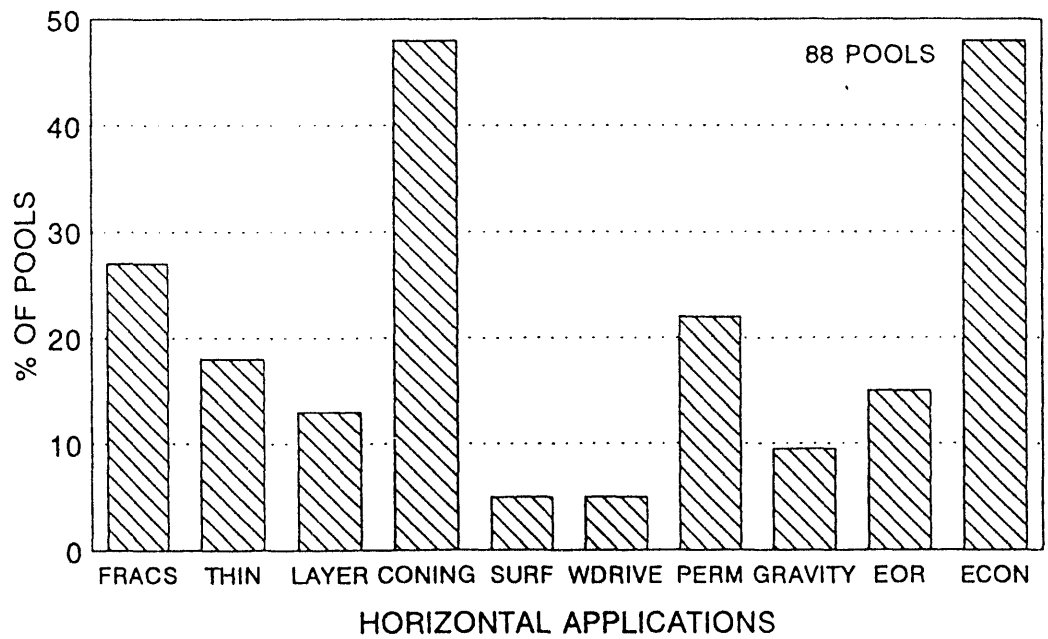

Figure 5. Canadian Horizontal Well Applications

The principal difference between the application distributions of Canada and the U.S.A. is that Canada has fewer intersecting fracture applications (27% versus 53%). Intersecting fractures is about twice as popular in the U.S.A. for both clastic and carbonate formations. Avoiding coning and favorable economics were the most popular Canadian applications, each at 48% of the pools. These three applications (fractures, coning, and economics) were the most popular in both the U.S.A. and Canada.

Technical and economic success of Canadian horizontal projects are summarized in Figure 6. Technical success has been above 90% in both countries. Economic success has generally been greater in Canada. Carbonate formations have had better economic success in Canada than in the U.S.A. (79% versus 45%). In clastics, economic success in both countries is about 60%. Heavy-oil Canadian projects have been economically successful more often than any other resource (92%).

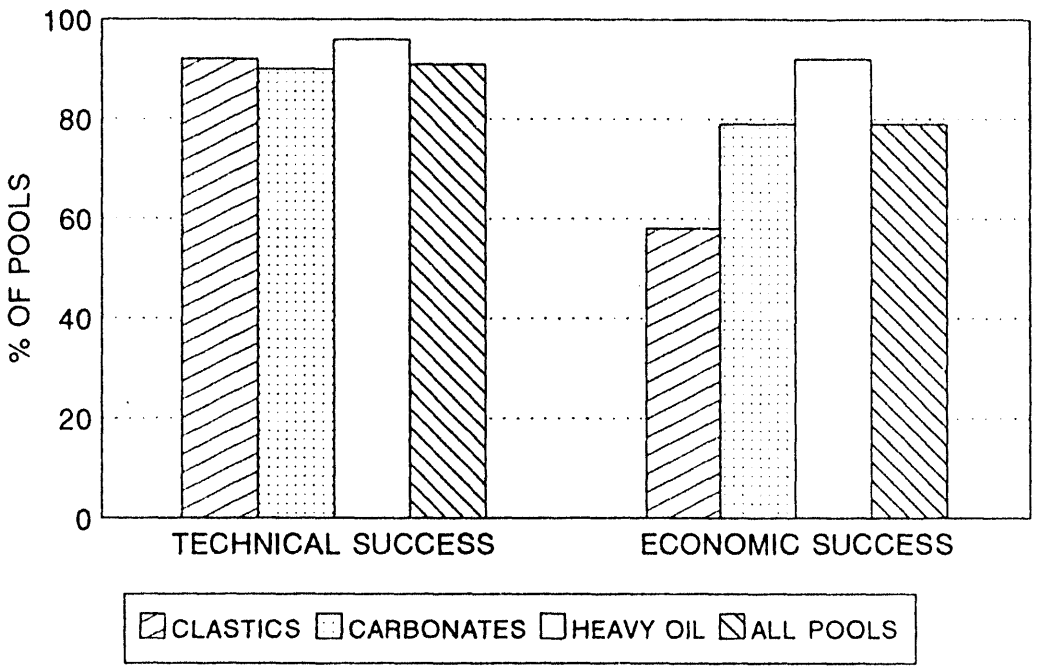

Figure 6. Technical and Economic Success of Canadian Pools

Additional data and results from Canada's experience with horizontal technology will be included in the final report. Conclusions are being formulated from Canadian experience with respect to lessons that can be applied effectively in the U.S.A.

William J. McDonald
Principal Investigator

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