

Fracture Optimization in the Valdemar Field Offshore Denmark

The Valdemar field contains a target reservoir that is a Lower Cretaceous “dirty chalk” containing up to 25% insoluble fines, porosity greater than 20%, and permeability below 0.5 md. Stimulations on several wells showed suboptimal production rates, which led to the conclusion that the Lower Cretaceous was not economically producible. An intensive study was therefore carried out to evaluate all aspects of the fracture design and implementation. This paper focuses on the aspects of proppant selection and adequate fracture-conductivity placement, with the goal of improving well productivity and cumulative recovery.

Completion Optimization

The Valdemar field is located in the Danish sector of the North Sea. The reservoir is characterized by a heterogeneous sequence of argillaceous chalk with thin beds of marl and claystone. The Lower Cretaceous reservoir is subdivided into 14 reservoir units on the basis of nanopaleontology and sequence stratigraphy. Because of the Valdemar field’s suboptimal production rates, an intensive study was carried out in 2008. Numerous experts were invited to view data, perform simulations, and offer recommendations. Eleven key items were identified as areas of potential improvement and are detailed further in the complete paper:

1. Improve the accuracy of treatment displacements.

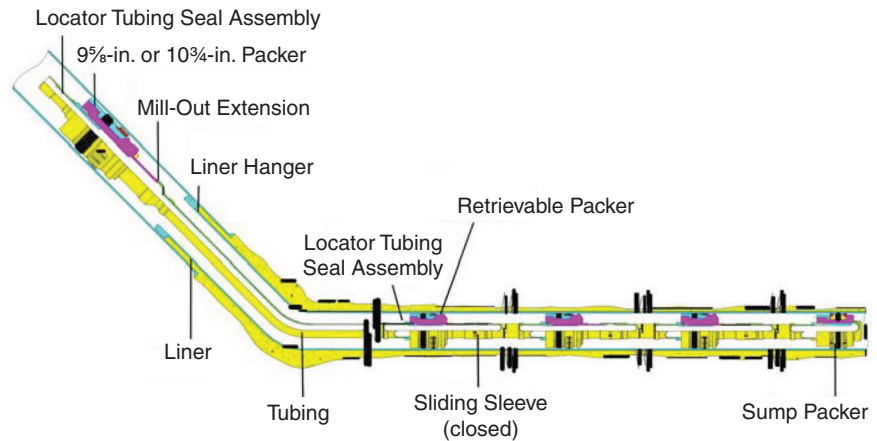


Fig. 1—The PSI system.

2. Implement aggressive fracturing-fluid-breaker designs.
3. Improve fracture conductivity by use of resieved sand.
4. Introduce real-time data acquisition and modeling.
5. Enhance interpretation of minifracture analysis.
6. Gather pressure data for after-closure analysis.
7. Minimize total fluids injected.
8. Assess the use of ceramic screened sliding sleeves for proppant-flowback control.
9. Supervise well cleanup.
10. Institute quality-control procedure for completion brine.
11. Introduce ceramic proppants for fracture-conductivity enhancement.

A study by a third-party consultant was conducted to determine the optimum fracture design. The study concluded that, for various reasons, the fractures were conductivity-limited, and that larger proppant was needed to improve effective fracture conductivity. This recommendation was furthered by implementing ceramic proppant, a process discussed in detail in the complete paper.

Field Implementation

In 2011, the Valdemar field was in the final stages of development. Wells VBA-6E and VBA-9 were the last planned for the structure and were located along the flanks of the reservoir; the former well is discussed in this summary. Because of late-life drilling, reservoir pressure had depleted from approximately 5,300 psi to approximately 4,260 psi along with thinner reservoir sections, which were also deeper.

Well VBA-6E Drilling and Completion.

Well VBA-6E was drilled, cased, and cemented with 9 5/8-in. casing to the top of the chalk, then drilled with an 8 1/2-in. bit to total depth at 24,088-ft measured depth (MD). A 7-in. liner was run to

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the expected maximum reach of 1¾-in. coiled tubing of 18,500-ft MD and cemented off-bottom. A 5-in. limited-entry predrilled liner was then run in the open hole to 23,892-ft MD. This section would be acidized with a controlled acid-jetting technique following the completion of the hydraulic-fracturing treatments. The propped fractures were treated using a perforation, stimulation, and isolation (PSI) system (Fig. 1). With this system, the first zone is tubing-conveyed-perforated, the guns are pulled out of the hole (POOH), and then the PSI system is run. Live guns are run in the well as part of the system, with (or typically without) a packer, and the end of the tubing is then positioned some 100 ft above the top perforation. The first fracture stage is performed and underflushed, and the excess proppant is immediately circulated out of the wellbore. The first isolation assembly is then placed on depth and set in place. This assembly consists of a packer, sliding sleeves, and seal assembly. Once set, the tool string is run to the next perforation interval, the zone is perforated, and the string is POOH to prepare the next isolation assembly and perforating guns. This assembly is then run into the well to 100 ft above the preceding perforations, and the process is repeated until all fractures are completed.

Well VBA-6E Propped-Fracture Design. Well VBA-6E was completed in June 2011 with the placement of 13 propped hydraulic fractures and one extended-reach predrilled limited-entry liner, which was subsequently acidized with hydrochloric acid. The fracture designs considered the use of resieved natural 20/40-mesh sand in the first five zones and then 16/20-mesh low-density ceramic proppant in the remaining eight fractures in order to compare the two proppants' performance. Of note, while the proposed sand fractures were de-

signed with 1,000,000 lbm of proppant each, the ceramic-proppant treatments were planned with only 500,000 lbm per fracture. To ensure each fracture was optimally designed and executed, breakdown, minifracure, and step-up/-down tests were performed before each fracture and then analyzed to redesign a tip-screenout fracture with proppant concentrations ending at 14 to 16 lbm of proppant added per gallon. Pump rates were limited to 32 bbl/min because of vessel capacity and line-velocity restrictions. Most of the stimulations ended with a net pressure approaching 500 psi.

The well was then flowed for clean-up and testing. A memory production-log test (PLT) was then performed to determine the relative contribution of each zone and to compare the actual formation response of the two differing proppant treatments to the simulated predictions. Favorable production results and the PLT log conclusively proved that the smaller-mass treatments with larger-diameter low-density ceramic proppant produced better than the sand-treated zones. For Well VBA-6E, the initial production rates were limited by restricted drawdown during initial cleanup. Once the well was fully on line, the fracture permeability became stable much more quickly than with the previous wells and at a significantly higher level of 8 darcies, evidencing a four- to eight-fold leap in fracture permeability because of the use of low-density ceramic proppant.

Well-Flow- and Buildup-Test Results

Upon completion of the stimulation and installation of the final upper completion, the wells were flowed and pressure buildups (PBUs) were performed. All wells had pressure and temperature gauges installed near the prospective-horizon true vertical depth. One critical

aspect was to review the PBU response to determine the characteristics of the pressure built up immediately upon closing in the wells. Looking at the PBU qualitatively, one can see significant differences in characteristics between Wells VBA-6E and VBA-9 vs. previous wells such as Well VBA-7. In contrast, Wells VBA-6E and VBA-9 have much lower immediate PBUs. A likely explanation for the observed difference in PBU behavior is a higher pressure drop under flowing conditions that resulted from convergence of flow in the transverse fractures at the connection to the wellbore in combination with the relatively lower conductivity provided by the sand propping agent used in VBA-7.

Conclusions

By recognizing the limitations of baseline conductivity measurements and using the effective conductivity for fracture design, hydraulic fractures in the Valdemar field were identified as conductivity-limited. A 15 to 20% cumulative production gain was projected by replacing 20/40-mesh sand by half the mass of larger 16/20-mesh low-density ceramic proppant. The recommendations of the optimization program were implemented in two wells. The PLT results confirmed the predictions; even though the total proppant volume was cut by 50%, the zonal contribution of the ceramic stimulated zones was in all cases better than that of the natural-sand-propped zones. The higher fracture conductivity obtained with the ceramic proppant at even one-half the sand mass, resulted in productivity improved by some 50%. Qualitative analysis of PBUs depicts a much-improved connection to the reservoir through more-conductive fractures. These completion-optimization measures allowed for the successful development in flank wells that otherwise might have been deemed uneconomic. **JPT**