In one North Sea gas field, production losses of up to 75% were reversed when sand control issues in several wellbores were remedied through the implementation of sand failure analysis and prediction modeling.

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Geomechanical sand failure and prediction studies can help empower operators to make more informed, cost-effective decisions, at every stage of field development and production.

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Sand production is a major problem in many clastic reservoirs worldwide, costing producers billions of dollars every year in lost or restricted production, and expensive well interventions. When stresses acting on a consolidated sandstone formation become sufficiently high, they can cause the rock matrix to break through compressive failure, releasing fragments and individual particles. As hydrocarbons flow through perforations out of the formation and into the wellbore, if fluid velocity is high enough, sand grains may be carried all the way to the surface. If, however, fluid velocity is low, sand will begin to deposit inside the wellbore, impeding the free flow of oil or gas.

In addition to lowering, or halting, hydrocarbon production altogether, sand abrasion and clogging can damage or destroy completion components, submersible pumps and other downhole equipment. Sanding can also interfere with wellbore access for remedial work, and can generate costly sand disposal problems.

Excessive stresses on a sandstone reservoir may be caused by the weight of overburden, superimposed tectonic stresses, and production or injection activities. In many cases, the effective stress increases as the reservoir depletes over time. Fluids within a reservoir actually provide support to the rock matrix, at least until fluid pressure declines along with production. Gradually, accumulated stress is transferred to the matrix, which may shatter and initiate sand production. This can occur unexpectedly, years after production begins. The relationship between stress and rock strength is one of the primary factors that influences sand failure. High-porosity rocks tend to be weaker than low-porosity rocks, due to less load-bearing material. However, rock strength also depends on the type and composition of cementation present, as well as oil and water saturation. Understanding all the factors involved in sand production can be difficult.

Clearly, having the ability to predict which intervals may suffer rock failure and trigger sand production, under what conditions, and at what point in time is becoming increasingly critical to economic success. Only with accurate sand prediction capabilities will operators be empowered to make proactive, timely, cost-effective sand management decisions. After years of research, laboratory testing and validation in fields worldwide, Schlumberger has developed an approach to sand failure analysis and prediction based on in-depth geomechanical modeling. In one North Sea gas field, this approach enabled GDF SUEZ to successfully re-establish economic sand-free production, Fig. 1.

K9 ROTLIEGENG GAS FIELD

In 1996, GDF SUEZ drilled the B1 exploration well in the K9ab-B Rotliegend (or K9) field in The Netherlands sector of the North Sea (Fig. 2), discovering natural gas. A year later, the B2 appraisal well was drilled in another fault block. After the production platform was installed, both wells were re-entered and completed. Production began in 1999. Several years later, two additional wells—B3 and B4—were
Drilled and completed, although B3 produced at a capacity below expectations.

After five years, B1 began producing sand. A screen was installed in 2004, but apparently collapsed in 2006, at which point the well suffered severe sand production again and was shut in. In 2007, B2 also began producing sand, which was controlled, initially, by producing at a lower drawdown pressure. Eventually, however, B2 was also abandoned. Shutting in two of the four producing wells resulted in the loss of 75% of the field’s total gas production. At that point, the company began investigating remedial sand control alternatives.

Normally, operators have three basic options: find ways of managing and disposing produced sand at the surface; reduce flowrates, so there is insufficient energy to mobilize sand grains along with fluids; or install a barrier or filter to prevent sand from passing through perforation tunnels into the wellbore. Types of mechanical sand control techniques include cased-hole gravel packs, high-rate water packs, frac packs, open-hole gravel packs, and stand-alone screens.

In unconsolidated formations, of course, screens are necessary from the very beginning of hydrocarbon production. Otherwise, most companies prefer screenless completions, which include oriented perforations and chemical consolidation, because productivity tends to be higher and initial costs lower. If sand production appears inevitable at some point, cautious operators may decide to install more expensive completions up front. Although these may ensure sand-free operations, perhaps for the life of the field, they may increase the well’s authority of expenditure AFE and sacrifice a certain amount of production. In addition, operators may apply pressure maintenance, injecting produced water back into a deeper section of the reservoir to forestall internal fluid pressure decline, and effectively minimize stress on the rock matrix. Determining if, or when, to implement some type of sand management can be challenging, and mistakes can be expensive.

In any case, the only way to predict how the formation will behave over time—and to select the most technically and financially appropriate completion strategy at different stages in the life of the field—is by gaining an accurate understanding of the reservoir’s mechanical rock properties, as well as the magnitude and orientation of stresses surrounding the borehole. To that end, GDF SUEZ engaged Schlumberger to conduct a thorough geomechanical study of K9 field’s reservoir section.

Sand failure analysis and prediction modeling was undertaken using Schlumberger’s proprietary Sand Management Advisor (SMA) technology. Developing, testing and refining the software has been underway for nearly two decades, to ensure that sand predictions match both laboratory experiments and field observations in clastic reservoirs of varying strengths, under many different stress scenarios. Operators have successfully applied this proven geomechanical sand failure model to avoid completing weak reservoir intervals; to select the right mechanical sand control mechanism for the reservoir, when necessary; to optimize the location, size and orientation of perforations; to predict the timing of sand production for specific completion and depletion scenarios; and to determine the drawdown pressure required to produce sand-free.

Although more oil companies realize the need for sand prediction studies, and outside consultants may offer fairly complex models, conventional approaches suffer from certain limitations and assumptions. Some employ overly simplified rules of thumb, for example: if the overburden load appears to exceed rock strength, they may routinely recommend a screened completion, even though it may not be strictly necessary until later in the reservoir lifecycle. To build a geomechanical model, many sand failure studies focus almost exclusively on rock strength, spending insufficient time and effort calculating the full range of stresses present, although both are equally critical to accurate sand prediction. Even when all key factors are considered, sand failure analysis is often carried out at a single depth, on the assumption that the...
A typical sand prediction for a problematic point within the K9 reservoir (Fig. 4) plots bottomhole flowing pressure—controlled by choke size at the surface—against reservoir pressure, which declines with production. The difference between these two represents the drawdown pressure. When bottomhole pressure (BHP) is greater than reservoir pressure at the selected depth, the well cannot produce at all. When BHP is less than reservoir pressure, the well will produce sand-free, only when the drawdown pressure remains within a specified safe zone, which can be maintained by choking. If the drawdown pressure exceeds a critical limit, then sand failure will occur. Sand failure intervals can be predicted at multiple depths along a continuous well profile, and these predictions can be made at different reservoir pressures.

Geomechanical and sand prediction modeling in the K9 field accurately matched key events at various times in the sanding history of both abandoned wells. One of the most important findings was that a single thin layer with low rock strength appeared to be the major contributor to overall sand production in both wellbores. The majority of other intervals within the reservoir remained relatively stable. However, modeling also predicted that failure would become likely in additional layers having even higher rock strength as the field continues to deplete. The study identified the zones of greatest risk.

To assess the validity of the sand prediction model, a downhole sand detection tool was run in wells B1, B2 and B3. The tool identified zones that were actually producing sand, and these zones exhibited a good match with the predicted zones, Fig. 5. As predicted, one thin interval was the primary source of sand failure. As a result, the study proceeded to investigate and recommend specific ways of isolating that zone and improving completion designs to achieve economic, sand-free pro-

Fig. 3. Sand failure analysis of the K9 reservoir depended on construction of a mechanical earth model, calibrated at each step with lab tests, core and log data. The Schlumberger Sand Management Advisor used this model for sand prediction.

Fig. 4. A typical sand prediction at a single depth within the reservoir indicates the critical drawdown pressure required to ensure sand-free production (green).
Tracked at the optimal azimuth and deviation indicated by the study. Although the best solution for an oriented perforation would have been horizontal, due to operational limitations the well was sidetracked at 50° inclination. After casing, new data were acquired, a petrophysical analysis was carried out, and the geomechanical model was updated. Sanding analysis on the revised model identified the safe interval, the perforation diameter was optimized for sand-free production, and the zone was perforated with oriented guns at an angle of 10°-15°-phasing. This type of oriented perforation allows a greater shot density by reducing the risk of interference and collapse between perforations and damage to casing. Well test performance was significantly better than the original B1 well, without producing any sand. Because the reservoir section remained accessible in the other three wells, cased-hole gravel pack completions with screens were designed for B2, B3 and B4. Following remedial work, the wells were started up slowly, and later production tested.

Since June 2008, all four wells have been producing sand-free at economic rates again. Indeed, production rates quickly returned to the field’s previous highest levels (see Fig. 1), effectively recovering the 75% total gas production lost due to severe sanding. Had the K9 field’s mechanical rock properties and stresses been better understood at an earlier stage of development, it might have been possible to avoid the sand production problem altogether.

Given the nominal cost of the study relative to its ultimate economic value, this type of geomechanical analysis has become standard practice for GDF SUEZ. In addition, for new fields the company often conducts this type of analysis much earlier in the development process. After drilling the first well in a field, if core analysis indicates a potential sanding problem, a proper geomechanical study will be conducted before drilling additional wells. This information facilitates the optimal placement of wells and selection of completions under various production and injection scenarios. In one oil field, for example, where produced water injection was planned, laboratory testing and the sand prediction study indicated that the reservoir interval could produce sand-free with oriented perforations. However, a different type of completion was necessary to prevent sand failure in the deeper interval chosen for injection. 

RESULTS ACHIEVED AND LESSONS LEARNED

In the B1 well, the safest way to ensure sand-free production was to design a screenless completion with selective, oriented perforations, avoiding any weak zones with a UCS below a specified value. However, because the well was vertical, oriented perforations would not be effective, as many orienting techniques rely on gravity and the well’s deviation to achieve the desired orientation. What’s more, the existing completion made the reservoir interval inaccessible. The well was sidetracked at the optimal azimuth and deviation indicated by the study. Although the best solution for an oriented perforation would have been horizontal, due to operational limitations the well was sidetracked at 50° inclination. After casing, new data were acquired, a petrophysical analysis was carried out, and the geomechanical model was updated. Sanding analysis on the revised model identified the safe interval, the perforation diameter was optimized for sand-free production, and the zone was perforated with oriented guns at an angle of 10°-15°-phasing. This type of oriented perforation allows a greater shot density by reducing the risk of interference and collapse between perforations and damage to casing. Well test performance was significantly better than the original B1 well, without producing any sand. Because the reservoir section remained accessible in the other three wells, cased-hole gravel pack completions with screens were designed for B2, B3 and B4. Following remedial work, the wells were started up slowly, and later production tested.

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ACKNOWLEDGEMENT
This article is adapted from SPE paper 168178-MS, “An innovative approach for sand management with downhole validation,” by authors Lex de Groot and Hilbrand Graven, of GDF SUEZ, and Surej Kumar Subbiah, of Schlumberger, which was presented at the SPE International Symposium and Exhibition on Formation Damage Control, on Feb. 26–28, 2014, in Lafayette, La.

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