INTELLIGENT COMPLETION SYSTEMS: RESERVOIR RATIONALE

Intelligent completion systems (ICS's) integrate reservoir sensors and remotely controllable inflow/outflow devices deployed permanently in the wellbore. The immediate benefits of such systems arise from minimization of interventions needed to ascertain critical changes and alter downhole flow conditions, particularly in offshore operations and subsea developments. Preliminary investigations indicate that longer-term tangible benefits also may be realized through punctuated or periodic modulation of an ICS.

CROSSFLOW

The first example is a deepwater gas field with two main producing intervals: a relatively thin, permeable interval with 3 Tcf of gas in place (GIP) and a relatively thick, tight interval with 7 Tcf of GIP. The intervals are separated by a thick layer of shale. The economic feasibility of this project largely depends on reducing the number of wells drilled, avoiding workovers and recompletions, and maximizing production from each well. Two development alternatives are field exploitation of the top interval only (not tapping 70% of the GIP) or exploitation of the two intervals by use of a dual completion, dedicated wells, hydraulic fracturing of the lower interval (aquifer communication), or commingled production (crossflow). An ICS can be a means to achieve commingled production without crossflow by modulating the production of the lower interval to maintain pressure parity with the top, more-productive interval. By use of material-balance and nodal techniques, the performance of the reservoir/wellbore system is forecast under a state of controlled commingled production. A stable plateau of gas production can be achieved, which is in sharp contrast with a declining production if only the top interval is exploited.

Flow Control. The proposed ICS architecture includes an intelligent flow-control device (IFCD) positioned between the layers and sensors that monitor the pressure of the two layers. Because the top layer is more productive, it will be produced without downhole restriction. The bottom layer initially can be shut off with the IFCD. The IFCD can be actuated later to allow a phased contribution from the bottom layer to attain a state of equilibrium between the two sandface pressures. The modulation mechanism of the IFCD is nondiscrete, allowing pressure parity between the two layers. As production proceeds and the pressure of the top interval declines, the IFCD can unchoke the bottom layer progressively. This process can continue until the sandface pressure is no longer sufficient to ensure the minimum required pressure at the wellhead, until the sandface pressure reaches the dewpoint pressure, or until some prescribed abandonment criterion is met. As the deliverability of the top layer declines, that of the bottom layer rises, producing a relatively constant plateau of gas production from the well. The bottom layer, in effect, compensates for the decline in the top layer because the bottom layer maintains an elevated reservoir pressure (owing to its larger volume and lower withdrawal rate) and yields an increasing deliverability as the well flowing pressure is reduced.

INJECTIVITY

The second example relates to control of the injection profile in a waterflood so that each zone intersected by the completed interval receives an injection volume commensurate with that zone's requisite critical rate. Injection beyond the critical rate results in premature breakthrough of injected water, while injection below this rate results in deceleration of the displacement process. The notion of critical rate is based on the interplay of viscous and gravitational forces and has particular relevance to dipping formations. To illustrate this concept, the authors examine the performance of a simple waterflood (a tilted two-layer reservoir with one producer and one injector). In the base case, the total injected water partitions naturally and spontaneously between the two layers; in the other case, each layer receives an amount equal to its critical rate with a simple ICS architecture. The performance of the two cases is compared in terms of the oil-recovery profile, cumulative water production, duration, and net-present-value characteristics.

Injection takes place in the updip direction. The layers are assumed to be noncommunicating. Endpoint relative permeability characteristics and viscosities are chosen to yield a mobility ratio, M, greater than unity (M=1.2), common in waterflood operations. Therefore, the displacement is only conditionally stable. If the injection rate exceeds the critical rate, the displacement is unstable, resulting in premature breakthrough of water (an incomplete or partial sweep of the reservoir when water breakthrough occurs).

This article is a synopsis of paper SPE 50587, "Intelligent Completion Systems—The Reservoir Rationale," by Y. Jalali, SPE, Schlumberger Wireline & Testing; T. Bussear, SPE, Baker Oil Tools; and S. Sharma, SPE, Schlumberger Wireline & Testing, prepared for presentation at the 1998 SPE European Petroleum Conference, The Hague, The Netherlands, 20–22 October.

The authors considered cases of uncontrolled and controlled injection. Both cases yield the same ultimate recovery because the frontal-advance theory for linear displacement in uniform-permeability fields does not account for the phenomenon of fingering, which results in bypassed oil. The difference between the cases is that one requires a larger quantity of water to displace the same quantity of oil, impacting flood duration and volume of produced water requiring processing and disposal.

Uncontrolled Injection. The apportioning of the total injection rate is in accordance with the injectivity indices of the two layers. The product of permeability and cross-sectional area for each layer provides a spontaneous injection rate of 10,000 B/D for the top layer and 3,000 B/D for the bottom layer compared with 5,000 and 8,000 B/D, respectively, in accordance with critical-rate considerations. Therefore, for the uncontrolled-injection case, the top layer should be flooded at supercritical rate and the bottom layer at subcritical rate.

Controlled Injection. The minimum architecture proposed to achieve a critical-rate split between the two layers consists of an IFCD positioned opposite the top layer and a flow-measurement unit (FMU). The FMU assembly contains a venturi nozzle and two permanent pressure gauges. The gauges monitor the pressures upstream of the nozzle (above it) and at the nozzle throat. For the minimum configuration, the injection rate is monitored at the surface. When injection is started, the IFCD is opened gradually and the rate passing through the FMU is monitored. The set point of the IFCD corresponds to an FMU rate equal to the critical rate of the bottom layer.

The uncontrolled-injection case exhibits a 3-year plateau averaging approximately 10,000 B/D followed by a 10-year plateau at approximately 2,500 B/D. (The sudden drop corresponds to depletion of the top layer.) The controlled-injection case exhibits a 5-year plateau at approximately 10,500 B/D. The cumulative recovery in both cases is identical. Deployment of downhole control accelerates the project from 4,456 to 1,789 days, and water production is substantially reduced from approximately 0.8 million to 0.17 million bbl.

CONCLUSIONS

No two reservoir-displacement problems are identical; therefore, the objective of this study has been to illustrate conceptual scenarios where application of simple ICS architectures could have a positive impact on the performance of the displacement process. From the preliminary investigation, layered formations appear to be promising fields for further exploration with respect to both production and injection problems. Problems of nonstratified formations, particularly in relation to coning and cresting behavior toward horizontal and multilateral wells, might also exhibit the virtues of downhole control. JPT

Please read the full-length paper for additional detail, illustrations, and references. The paper from which the synopsis has been taken has not been peer reviewed.