Increasing Confidence in Production Forecasting Through Risk-Based Integrated Asset Modeling: Captain Field Case Study

To assist probabilistic forecasting and decision making for the Captain North Sea heavy-oil asset, Chevron developed an integrated asset model (IAM). This model includes probabilistic predictions of facilities performance and production, enabling decision-risk analysis for strategic and operational decisions. The IAM includes risk-based oil-, gas-, and water-production forecasts and cash flows. These forecasts take full account of facilities constraints and uncertainties in reservoir and operational parameters through links to decision-risk-analysis software.

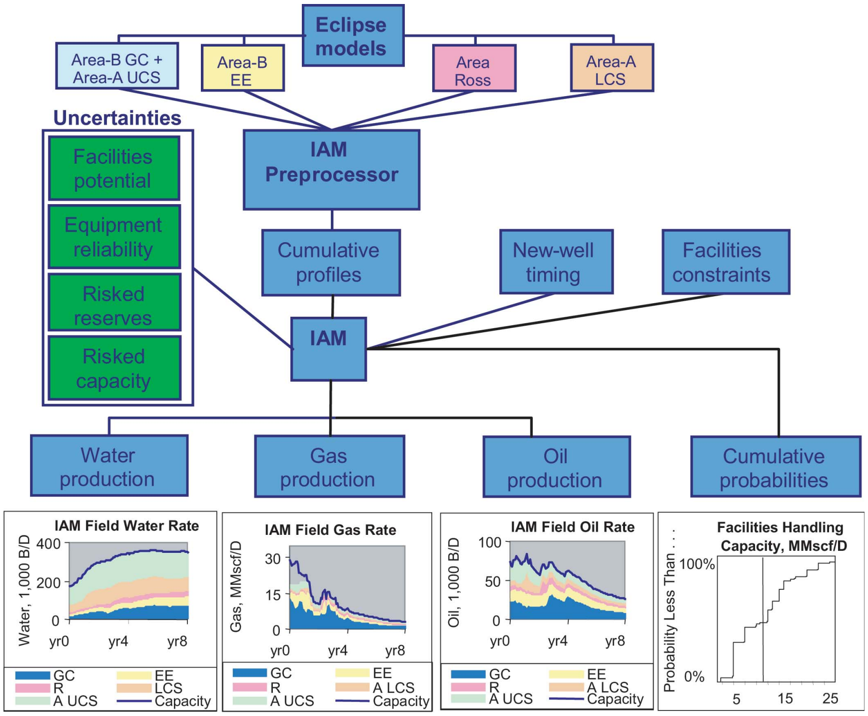

Fig. 1—IAM process outline.

Introduction

The Captain field is a phased development comprising Areas A and B. The field produces high-viscosity oil, with separation taking place on a floating production, storage, and offloading vessel. Critical processing interdependencies, single-train separation with limited redundancy, and gas- and water-handling constraints require facilities downtime with significant effect on production projections. The five producing areas in the field produce from three reservoir units: upper Captain sand (UCS), lower Captain sand (LCS), and the Ross (R). Production consists of the three fluid phases—oil, water, and gas. Produced gas includes gas-cap (GC) and solution gas. Electrical or hydraulic submersible pumps provide artificial lift in every well. All produced water from the field is reinjected into the reservoir, with a portion of it used to power the hydraulic submersible pumps. The dynamic subsurface behavior is simulated with four separate reservoir-simulation models.

- Area-A UCS plus Area-B GC.
- Area-A LCS.
- Area-B eastern extension (EE).
- Ross.

Key to the Captain IAM approach is that a wide range of different reservoir simulations, time dependencies, and production rates from each well can be reconstructed adequately from a two-parameter response surface that itself is not a function of time. This response surface is the phase rate tabulated as a function of total reservoir rate and cumulative production.

To investigate this assumption, a response surface for one of the Captain reservoirs was constructed and then used to predict well behavior during different well choke-back scenarios. This response-surface approach can be used to forecast strategies not covered in simulation runs. The IAM has facilitated estimating the effect of uncertainties in reservoir or operational parameters and linking to decision-risk-analysis software. The IAM analysis tool has been used to help with the following.

- Completing the second development phase.
- Selecting a concept for a third development phase.
- Providing credible probabilistic production forecasts.
- Developing operational and debottlenecking decisions.

This article, written by Technology Editor Dennis Denney, contains highlights of paper SPE 99937, "Increasing Confidence in Production Forecasting Through Risk-Based Integrated Asset Modeling: Captain Field Case Study," by ***L.M. Wickens,*** *SPE, RPS Energy, and* ***G. De Jonge,*** *SPE, Chevron Upstream Europe, prepared for the 2006 SPE Europec/EAGE Annual Conference and Exhibition, Vienna, 12–15 June.*

For a limited time, the full-length paper is available free to SPE members at **www.spe.org/jpt***. The paper has not been peer reviewed.*

Fig. 1 shows a schematic overview of the IAM and how it links separate reservoir-simulation models as well as probabilistic facilities models.

A model of the facilities is used to generate risked facilities-throughput-capacity data on the basis of equipment reliability and available power. Usually, this model would be used as a standalone unit to generate 10, 50, and 90% probability values for facilities-throughput capacity, which then are entered into the IAM. However, if necessary and run-time constraints are not restrictive, it also can be linked directly to the IAM.

At each timestep, the IAM calculation includes the following.

- Updating current cumulative free-gas and oil production, and then using these values to determine the corresponding free-gas-, oil-, and water-production capacities from simulation-based lookup tables.
- Applying field free-gas- and water-production constraints by choking back wells on the basis of a gas/oil-ratio and water-cut well-priority order for the timestep determined for all Captain wells.

Production Model

For oil and water production, the response surfaces comprise oil- and water-production rates for each well as a function of well cumulative oil production and the current well total reservoir rate. Transient behavior will occur, but the pressure drawdown applies over longer timescales than these transients. The pressure drop is dominated by near-wellbore behavior, perhaps less than 30 ft away from the well, and pressure transients will traverse this region relatively rapidly.

The fixed geometric aspects can be the same as that entered into the reservoir simulator so that many runs for a well (or group of wells) draining a particular part of the reservoir at different rates can be recast as a single response surface. The oil and water rates at the well also depend on both the pressure drawdown and the geometric distribution of fluid saturations. These rates depend on pressure differences, rather than absolute values of pressure, so that their applicability will not be sensitive to changes in reservoir pressure. The final flow variable, free-gas rate into a well from a GC, will depend on the extent of gas cusping, which itself is related to the total reservoir flow rate above the critical cusping rate.

The response surfaces can be based on a limited number of reservoir-simulation runs at, for example, four different volumetric-flow rates. These runs include the actual well geometry and rock matrix, but the results, rather than being a function of time, are summarized as lookup tables that are a function of either cumulative oil or free-gas production. For a given well, the appropriate oil-, water-, and free-gas-flow rates then can be computed by specifying just well total reservoir rate and cumulative oil production or well total reservoir rate and cumulative free-gas production. Intermediate values of well total reservoir rate (not covered by the simulation runs) can be interpolated from the lookup tables. Wells (or well groups) can be choked back temporarily, even though this procedure was not specified in any of the four runs that provided data. This ability of the response surface to predict a wide range of simulator transient behavior effectively means that it provides an acceptable approximation of the simulator.

Validation of the Response-Surface Approach. To demonstrate the validity of specifying well behavior within the IAM by use of cumulative-production-based lookup tables, data for Well GC4 were used from four runs of the Captain simulation model. Each run had all wells producing at the same nominal total reservoir rate, corresponding to four different values of total reservoir rate.

Excellent agreement between the reservoir simulator and the IAM approach was obtained for both water and free-gas rates, during both well choke back and well opening. Also, the increase in critical reservoir rate at which free gas stops flowing was predicted.

Gas/Oil-Reserves and Capacity Variation. Free-gas-reserves variation resulting from initial-gas-in-place uncertainty applies only to reserves at the start date for the data tables. If the reserves at this start date are multiplied by a free-gas factor, the result is modeled by adjusting the cumulative gas values in the lookup tables.

Simulator-Data Overview

A preprocessor spreadsheet containing a macro was used to extract the necessary data from simulator output files, to set up tables in the correct format, and to display charts. Table interpolation substantially reduced the number of data points from the simulator data files. To generate the tables, a simulation is set up to calculate the potential capacity for a well by use of a downhole-flow-rate boundary condition. If a well's bottomhole pressure (BHP) in the simulator dropped below a preset value, then its flow rate was determined with a BHP boundary condition. The runs used to generate these data sets should have no facilities constraints because these will be applied within the IAM. Separate lookup tables are required for each well.

A well BHP table is used to check whether the well has changed from flow-rate to BHP control within the simulator. Therefore, the following tables were extracted from output files for each well.

- Maximum oil-production rate vs. cumulative oil production.
- Maximum water-production rate vs. cumulative oil production.
- BHP vs. cumulative oil production.

In addition, for a reservoir having a GC, a data table containing maximum free-gas-production rate vs. cumulative free-gas production from the well was required for each well in the reservoir.

Facilities Model

The facilities component of the IAM computes the facilities gas- and water-handling capacity, given equipment availability. If the total power generation is less than the total power requirement, then currently available equipment will be turned off in a predetermined priority order. Given this new facilities scenario, the IAM will determine the available facilities gas- and water-throughput potential. With this approach, cumulative probability graphs of facilities gas-throughput potential can be generated for risked facilities scenarios by passing indicators from a decision tree to the IAM.

Conclusions

The IAM is able to capture interdependencies of the Captain reservoir models and facilities performance. The validated model has been particularly successful in providing probabilistic production forecasts. IAM applications included the following.

- Well workover screening.
- Infill-drilling-campaign timing.
- Sensitivity of oil reserves to gas-in-place values, facilities performance, and well life.
- Plant debottlenecking. JPT