A stochastic reservoir description model is defined and a simulation procedure is implemented. The model is based on a discrete facies model with a continuous model for petrophysical variables superimposed. The facies model characterizes the reservoir as discrete facies with user-defined sizes and interactions. The petrophysical variables are defined as porosity, permeabilities and initial saturations. Their characteristics are dependent on the facies in which they occur and they may be correlated. The petrophysical variables constitute the input to the reservoir production simulators. On the basis of the stochastic model and with conditioning on available well information, several realizations of the reservoir description can be provided through simulation.

The reservoir description model is used to study the effects of varying heterogeneities on gas injection on a vertical cross-section. For a given set of model parameters, and observed values in two wells, a number of cross-section descriptions are simulated, with varying net to gross ratios, porosities and permeabilities. Gas injection with a fixed set of production parameters is simulated on each cross-section, and empirical distributions of breakthrough times and recoveries are calculated.

The results show that the variability inherent in the description of the cross-section gives rise to a sizable variability in production, so that no single realization or average is capable of giving representative results. Hence the distributions of the production results become important. Stochastic simulation appears as a simple, though laborious, way of calculating these distributions. The representability of the calculated, empirical distributions as indicators of the possible outcomes of a production scheme depends on the number of realizations chosen as well as the ability of the stochastic model to represent the physical variability of the porous medium.

**INTRODUCTION**

Reservoir production simulation* is used to calculate reservoir performance and estimate recovery for a given production scheme, to evaluate the effects of recovery on altered operating conditions, and to compare economics of different recovery methods. To give reliable results, the simulations must be based on accurate numerical models of the fluids involved, their dynamical behaviour, and the porous medium in which they flow. Today’s simulations are relatively advanced in their ability to calculate fluid properties, and much effort has been spent in designing numerical models of fluid flow. On the other hand, the reservoir description models used in the simulations have often been overly simplified, e.g. by assigning a single set of rock parameters to large regions of a reservoir, without taking the heterogeneities into consideration. Studies of enhanced oil-recovery methods have, however, led to an increasing awareness of the significance of an accurate reservoir description for the predictability of reservoir potential. Improved reservoir description methods embody several features, viz.

- improved techniques for measuring reservoir parameters;
- development of refined methods for inferring reservoir properties from available measurements;

*The term *simulation* has different meanings when used for flow forecasts by the petroleum engineer and for reservoir description by the geostatistician. To distinguish them we use production simulation in the first meaning and description simulation in the latter.

*North Sea Oil and Gas Reservoirs—II*
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• a greater knowledge of the effects of various types of rock variability on displacement processes;
• the ability to represent and utilize the improved reservoir descriptions in production simulators.

Our knowledge about a reservoir under study will always remain incomplete. Hence the objective should be to establish a model characterizing the reservoir parameters with associated uncertainties. Simulations based on this model, assuming consistency with observed data, provide possible realizations of the reservoir parameters. In this contribution a stochastic approach is used taking both facies dependence and spatial variability in the petrophysical parameters into account.

Stochastic reservoir modelling allows a quantification of uncertainties in reservoir parameters by defining them as stochastic variables. Hence, the results of a production simulation—pressures, saturations, breakthrough times, gas or water cuts, recovery—also become stochastic variables, and a study of their statistical properties can lead to a quantification of uncertainties in predicted production results as functions of uncertainties in the reservoir description. To our knowledge, only a few papers in the petroleum literature have addressed this problem (Brown and Smith, 1984; Augedal et al., 1986; Hewett and Behrens, 1988). Analytical results are scarce, based on linearizations, and applicable to one-phase flow only. In some situations, stochastic description simulations can be used. Reservoir production simulations are performed on a set of realizations, and empirical distributions for the production results are obtained. We present an example of this kind. The example concerns gas injection on a cross-section. We calculate empirical distributions of production results for varying facies distributions, porosities, and permeabilities.

In the following section the stochastic model for reservoir description is defined. The underlying assumptions, conditioning and program systems are presented. The next section contains an outline on the assumptions on which the production simulator is based. The results from the example are then presented and discussed. The final section contains some concluding remarks.

**A MODEL FOR RESERVOIR DESCRIPTION**

In the computer program system presented here, a discrete process, which may be associated with facies, is overlaid a continuous process having properties conditioned on the actual facies. Conditioning on actual observations in wells can also be performed. Various realizations based on this model concept can be generated and used as input parameters to the reservoir production simulator in order to evaluate its sensitivity to uncertainty in the reservoir description.

In the presentation, it is convenient to divide the variables into two categories.
• Primary variables represent the reservoir characteristics that have direct influence on the flow through the reservoir. Hence, they are input parameters to the reservoir production simulators. These variables are modelled as continuous variables in the three-dimensional (3D) space with model characteristics dependent on the secondary variables present. Relevant primary variables are porosity, initial water saturation and absolute permeability.
• Secondary variables represent reservoir characteristics that influence the value of the primary variables, and hence indirectly the flow rate. The secondary variables may represent a facies model. This entails modelling of reservoir units having reasonably homogeneous characteristics. These facies are modelled as discrete processes in 3D space.

**Model assumptions**

In the presentation, the reservoir volume is denoted $V$; $x$ is a location in the reservoir; and $h$ is a shift vector. It seems natural to present the secondary variables first:

**Secondary variables**

The following discrete stochastic model is used for the facies variables

$$\{L(x); x \in V \}$$

with

$$L(x) \in \{l^0, l^1, l^2\}$$

Each location in the reservoir can be assigned one, and only one, facies. The facies model distinguishes three types of facies (see Fig. 1):

- **Matrix facies**, $l^0$, which constitutes the reservoir matrix. It can be considered the major sedimentation process in the creation of the reservoir.
- **Eroding facies**, $l^1$, which are bodies distributed in the reservoir. They can be considered as eroded into the matrix facies. Each facies body has a given shape and a size according to a specified probability distribution for size, $F_s(v)$. Each body also has a reference location in $V$. These reference locations are distributed in $V$ according to a point process with a pairwise interaction function $r_l(h)$. This makes it possible to simulate repulsion between the bodies. The total number of eroding facies bodies is determined by specifying, $n_l^1$, the net-to-gross ratio.
- **Barrier facies**, $l^2$, which are horizontal planes in the reservoir. They can be associated with barriers in the reservoir caused by either shales or carbonate cementation. Each barrier has a given shape and an area

**Fig. 1.** Facies types generated by the facies model.