ISAPP Symposium

5 and 6 November 2013

Venue:

Faculty of Civil Engineering and Geosciences
Delft University of Technology

Tuesday 5 November 2013

9:00	**Registration**			
9:30	Braal	Richard	TNO	ISAPP Status Overview
9:45	Jansen	Jan Dirk	TUD	ISAPP and Recovery Factory Technical Status Overview
10:20	Schutte	Koen	TUD	Scaling of shape & size of particle agglomerates with bond strength, break-up mechanism and flow conditions. Asphaltenes: to deposit or not to deposit?
10:45	**Coffee/tea**			
11:15	Renes	Walter	TNO	Real-time optimization of a maturing North Sea gas asset with production constraints
11:50	Mansoori Habib Abadi	Mehdi	TUD	Identification of reservoir characteristics from generalized well test data
12:15	Cardoso	Marco Antonio	Petro-bras	Integrated reservoir modeling and production optimization
12:50	**Lunch**			in the Exhibition room
13:50	Van der Meer	Jakolien	TUD	Numerical issues concerning the simulation of foam EOR
14:05	Ameri Ghasrodashti	Amin	TUD	Miscible gas oil gravity drainage: experiments and modelling
14:30	Gelderblom	Paul	Shell	Probabilistic history matching on flow-relevant ensembles
15:05	Sebacher	Bogdan	TUD	An adaptive plurigaussian truncation scheme for geological uncertainty quantification using EnKF
15:30	**Coffee/tea**			
16:00	Ek	Torbjørn	Statoil	Geologically realistic facies updates on a North Sea field
16:35	Maris	Cristian	TUD	Feature space history matching uncertainty preservation using iterative methods
17:00	Hanea	Remus	Statoil	Optimization of well planning under geological uncertainties for a North Sea field
18:30	**Dinner**			

Wednesday 6 November

9:00	**Registration**			
9:30	Fonseca	Rahul	TUD	Robust ensemble-based multi-objective optimization and insights into the objective function search space
9:55	Siraj	Mohsin	TU/e	A robust hierarchical approach to life-cycle optimization
10:10	Insuasty	Edwin	TU/e	Introduction talk and control relevant modeling of oil reservoirs
10:25	Leeuwenburgh	Olwijn	TNO	Some new developments in ensemble-based life-cycle optimization
11:00	**Coffee/tea**			
11:30	Della Rossa	Ernesto	ENI	Data assimilation and ensemble optimization: real experiences and open issues
12:05	Barros	Eduardo	TUD	Value of information in closed-loop reservoir management
12:30	Kahrobaei	Siavash	TUD	Hidden Information in Ill-Posed Inverse Problems
12:55	**Lunch**			in the Exhibition room
14:00	Van Essen	Gijs	Shell	AHM in practice: the challenge of matching water measurements
14:35	Szklarz	Slawomir	TUD	POD-DEIM reduced reservoir simulation
15:00	Popa	Tudor	TUD	History matching exercise for the Norne field
15:25	Hegen	Dries	TNO	Closing remarks
15:30	**Drinks**			in the Exhibition room
16:00	**Steering Committee**			in room 03.270

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9:30 - 9:45 **Richard Braal (TNO):**
ISAPP status overview

9:45 - 10:20 **Jan Dirk Jansen (TU Delft):**
ISAPP and recovery factory technical status overview

10:20 - 10:45 **Koen Schutte (TU Delft), Aris Twerda (TU Delft/TNO), Ruud Henkes (TU Delft):**
Scaling of shape & size of particle agglomerates with bond strength, break-up mechanism and flow conditions. Asphaltenes: to deposit or not to deposit?

The deposition of asphaltenes is a major concern in crude oil production, as it diminishes the oil production rate. The aim of our project is to acquire a better understanding on the fundamentals of the influence of flow on asphaltene agglomeration, and on its subsequent deposition. So far, our research has been focussed on the formation and break-up of agglomerates, using a primary-particle based numerical model that we implemented in an existing channel flow solver. Currently, this model is being extended to include the effects of deposition at the confinements of the flow domain.
In absence of deposition, agglomeration and break-up will balance each other, such that a steady-state is reached. In the presentation, we will show how the properties of the steady-state agglomerate population, such as the shape and the size distribution, depend on the problem parameters. These parameters include the strength of the bonds formed between the primary particles, the mechanism of agglomerate break-up considered, and the Reynolds number. Some preliminary results on agglomerate deposition will also be included in the presentation.

10:45 - 11:15 ***Coffee/tea break***

11:15 - 11:50 **Ruud van der Linden, Tom Busking, Walter Renes (TNO):**
Real-time optimization of a maturing North Sea gas asset with production constraints

As gas and oil fields mature their operation becomes increasingly more complex, due to complex process dynamics, like slugging, gas coning, water breakthrough, salt or hydrate deposition. Moreover these phenomena also lead to production constraints in the upstream facilities. This complexity asks for operator support in how to optimally operate such an asset.
In this paper we explore how, based on physical models of reservoirs, wells and top side separation and compression equipment, real-time optimization may be used in optimal operation of a maturing asset showing complex dynamic behavior and top side compressor constraints. In a joint industry project of Wintershall, GDF, EBN, Siemens and TNO the applicability of Real-Time Optimization is explored. Real-time optimization will be demonstrated on a maturing North Sea off-shore gas production asset consisting of eight wells and two separator and compression trains.
The current results show how the optimization problem has been defined and implemented in a real-time architecture. First results are shown realizing the gas production set point and minimizing compressor power, while the production of individual wells suffer from degrading performance and (unplanned) shut-ins.
The optimizer computes how the production must be dynamically distributed over the wells and how the compressor trains must be operated.

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11:50 - 12:15 Mehdi Mansoori Habib Abadi (TU Delft):
Identification of reservoir characteristics from generalized well test data

Well test analysis is generalized for variable wellbore flow rate and pressure measurement data through system identification framework. To this end, the wellbore and reservoir are modelled as bilaterally coupled systems, and it is shown that closed-loop identification techniques can filter the wellbore effects from the data and identify the reservoir dynamical model separately. Finally the physical properties of the reservoir are estimated in frequency domain utilizing the identified reservoir model.

12:15 - 12:50 Marco Antonio Cardoso, Alexandre Emerick (Petrobras):
Integrated reservoir modeling and production optimization

Reservoir management is a process that can be improved by valuing opportunities offered by emerging technologies. Some technologies, such as permanent seismic sensors for real time data acquisition and down-hole well controls can significantly support the asset team to monitor and predict the movement of reservoir fluids. Fluid monitoring helps the team to locate bypassed oil, avoid premature water breakthrough, optimize infill well locations, etc. Software-based technologies, such as data assimilation and optimization methods permit the calibration of the mathematical subsurface model to reproduce the past performance of the reservoir, in addition to predict the future production. In my talk I will give an overview of Petrobras' Integrated Modeling Project. The objective of this project is the development and application of computational techniques for modeling, visualization and optimization of reservoirs and production systems. Examples of application of different techniques, such as data assimilation, integrated reservoir-production modeling and production optimization will be presented.

12:50 - 13.50 ***Lunch in the Exhibition room***

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13:50 - 14:05 Jakolien van der Meer, Daniel van Odyck, Jan Dirk Jansen, Kees Vuik (TU Delft):
Numerical issues concerning the simulation of foam EOR

If secondary hydrocarbon recovery methods, like water flooding, fail because of the occurrence of viscous fingering one can turn to an enhanced oil recovery method (EOR) like the injection of foam. The generation of foam can be described by a set of partial differential equations with strongly nonlinear functions, which impose challenges for the numerical modeling. Former studies by Zanganeh (2011) and Ashoori (2012) show the occurrence of strongly temporally oscillating solutions when using forward simulation models, that are entirely due to discretization artifacts. To analyze these problems, we study the dynamics of a simple foam model based on the Buckley-Leverett equation. Whereas the Buckley-Leverett flux is a smooth function of water saturation, the foam will cause a rapid increase of the flux function over a very small saturation scale. Consequently the derivatives of the flux function can become extremely large and impose a severe constraint on the time step due to the CFL condition.

14:05 - 14:30 Amin Amerighasrodashti (TU Delft):
Miscible gas oil gravity drainage: experiments and modelling

There is no doubt that the energy demand will grow substantially in both the short and medium-long term. Therefore, new energy sources are required to respond and meet this energy demand. A large part (20-30%) of the oil resources is present in naturally fractured reservoirs (NFRs). However, a large fraction of these NFRs do not show high production performance as most of the oil resides in the matrix blocks outside the fracture network from which it is difficult to recover, unless enhanced oil recovery techniques are applied. Even though gas injection has been traditionally considered as an ineffective method to enhance oil recovery from NFRs, some reservoirs are suitable for gas injection when gas oil gravity drainage (GOGD) enhances its efficiency.
A series of experiments were conducted to examine the performance of the non-equilibrium gas injection process in naturally fractured reservoirs at different miscibility conditions. To this end, different gas injection schemes have been examined using different gases including CO2, N2 and a synthetic flue gas composing of 20% (v/v) CO2 and 80% (v/v) N2. This makes it possible to examine the matrix-fracture interactions during gas injection at different miscibility conditions.
The mass transfer between matrix and fracture system at fully miscible conditions was also studied using different oil-solvent pairs. The interactions between matrix and fracture system was visualized for solvent injection by means of CT-Scanning, which can be used to validate theories of enhanced transfer in fractured media.
A fully compositional numerical model was also developed to reproduce the experimental results. The model was then used to examine the effect of different parameters on the performance of GOGD at different conditions.

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14:30 - 15:05 Eduardo Jimenez, Gijs van Essen, Tzu-Hao Yeh, Chaohui Chen, Paul Gelderblom (Shell), Lior Horesh (IBM):
Probabilistic history matching on flow-relevant ensembles

Predicting reservoir performance is a matter of uttermost importance to the industry. Whatever measurements and (geological) knowledge about the reservoir are available, there will always remain uncertainty about the detailed geological structure of the reservoir and its impact on reservoir performance.
One way to incorporate that uncertainty in predictions is to work with an ensemble of models that span the full geological uncertainty space. This should incorporate realizations of facies distributions that span the conceptual geology inherent to the subsurface, and also should include structural components ranging from horizons, "sub"-layering between horizons, fault throws, etc. This would require hundreds of thousands of models (10^4-10^6) and the subsequent flow simulation and incorporation of dynamic data (production+4D Seismic) for all these models is currently infeasible (without intensive HPC).
Our vision is to handle uncertainty with a smaller, flow-relevant ensemble. This contains in the order of 10^2 to 10^3 realizations taken from the geological model space, and screened and filtered using 'dynamic fingerprinting' to represent the entire range of dynamic uncertainties.
In 2010 we started a R&D collaboration with IBM where one of the main goals was to bring IBM expertise (biometrics, inverse modeling, data mining, optimization) towards finding screening and sampling criteria to generate an appropriate ensemble of flow-relevant geological model realizations on which dynamic simulations can be considered.
Often different static model realizations may correspond to very similar flow patterns. Such models are likely to entail similar production forecasts. We use *flow indicators* or *dynamic fingerprints* to identify clusters of dynamically similar models. Typical flow indicators are mass fluxes or time of flight. These can be extracted doing a short simulation, and therefore substantially faster than the entire history matching process.
In order to manage the large dimension of the flow indicators we propose their representation by means of coefficients of a spanning set of the indicators (a compact Singular Value Decomposition). Each realization's indicator can then be completely captured by a small number of coefficients. Once the realizations' indicators are captured by the reduced space dominant coefficients, hierarchical clustering is performed. As a result, we end up with a small set of clusters. Each cluster aggregates a set of model realizations that despite their apparent difference in the model space, all correspond to similar principal flow trends. A representative from each cluster is then chosen to be used for the history matching process rather than the entire set within the cluster.

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15:05 - 15:30 **Bogdan Sebacher (TU Delft/ Technical University of Civil Engineering, Bucharest), Remus Hanea (Statoil), Arnold Heemink (TU Delft):**
An adaptive plurigaussian truncation scheme for geological uncertainty quantification using EnKF

The work presented here introduces a generalized framework (compared with the methodologies present in the most recent publication on the topic) for taking into account geological uncertainties, e.g. facies distribution in particular. It is based on the idea where a categorical variable (facies type) is parameterized using probabilities maps in order to able to be updated based on production data and facies observations into an Ensemble Kalman Filter approach. The novelty of the presented work resides in the introduction of a new and more general framework of the plurigaussian truncation simulation model with the truncation map defined in the probability space. This truncation map allows the generation (using Gaussian random fields) an ensemble of facies distributions that are able to reproduce almost perfect the initial knowledge of experts and to constraint the ensemble accordingly. This is the first time when the experts knowledge is directly taken into account, updated and preserved throughout the whole assisted history matching process. This also solves the issue of not having an extra iterative process in the EnKF update used for constraining the values of the ensemble on the facies distribution at the wells. This is done intrinsic in the new approach.

15:30 - 16:00 ***Coffee/tea break***

16:00 - 16:35 **Torbjørn Ek, Remus Hanea, Lars Hustoft, Daniel Berge Sollien, Jon Sætrom (Statoil):**
Geologically realistic facies updates on a North Sea field

This work introduces a general framework for taking into account geological uncertainties, facies distribution in particular. It is based on the idea of parameterizing the facies types (a categorical variable) using probabilities maps in order to able to update (the facies) based on production data, well observations and seismic information.
We use an ensemble based framework which allows for quantifying, handling and propagating the uncertainties by using multiple realizations (Ensemble Kalman Smoother approach). The novelty of the presented work resides in the introduction of a new and more general framework of the plurigaussian truncation simulation model with the truncation map defined in the probability space.
This truncation map allows for generating (using Gaussian random fields) an ensemble of facies realizations (facies probabilities maps) that are able to reproduce the initial knowledge of experts and to constrain the ensemble accordingly. This is the first time when the experts knowledge is directly taken into account, updated and kept over the whole process of assisted history matching.
This approach is tested on a North Sea field case. Here, the three types of facies present in the reservoir (crevasses, channels and the floodplain) are being updated consistent with the initial geological information about the facies proportions and geo-statistical properties . We will show the impact of this approach on history matching the pressure data in a difficult sector of the reservoir, where the geological uncertainties plays an important role.

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16:35 - 17:00 **Cristian Maris (TU Delft), Andreas Stordal (IRIS, International Research Institute of Stavanger, Norway):**
Feature space history matching uncertainty preservation using iterative methods

Reproducing and preserving realistic geological and structural features in ensemble-based History Matching has been tackled recently by using different feature-space and so-called kernel methods. Our results with a distance-based, feature-space ensemble reparameterization EnKF were encouraging in this respect. However, uncertainty preservation is lacking, the method being just as or even more prone to the issue of ensemble collapse than the traditional EnKF. We thus propose to use iterative methods in conjunction with ensemble resampling in order to address this issue, while preserving the advantage of better reproduction of certain geological features. Conditional ensemble resampling will both provide models that are consistent with the features to be preserved, as well as maintain ensemble variability in the areas of the model where there is less information available from observations.

17:00 - 17:35 **Remus Hanea, Lars Hustoft, Shunping Liu, Torbjørn Ek, Jon Sætrom (Statoil):**
Optimization of well planning under geological uncertainties for a North Sea field

The main objective in any reservoir development plan is to achieve maximum reservoir exploitation or actually maximum estimated net present value (ENPV). Hence, an optimal well planning scheme needs to be generated. One of the main aspects to consider is the reservoir characterization and the associated uncertainties. The geological description of the reservoir is uncertain, the uncertainty is associated both with the structural framework and with the spatial distribution of the facies, permeability, porosity and fluid saturations. In the well planning phase it is important to quantify this uncertainty, and furthermore to propagate it and handle it in prediction mode. The next logical step is to move towards linking the updated reservoir models with an economic (NPV) constraint.
Here we present a new approach where the drilling of the wells is optimized and the geological uncertainties are taken into account when models are conditioned on observations. We will focus on combining the average permeability and oil volume (in well-penetrated and surroundings cells) across all realizations to estimate the "potential" of each well. Then we open the wells accordingly to their "potential". The final product will supply an optimized order of drilling the wells, with the ability to automatically perform geo-steering or side-tracking of wells in each model realisation under the constrain to match a possible forecasted production profile.

18:30 ***Dinner***

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9:30 - 9:55 Rahul Fonseca (TU Delft), Olwijn Leeuwenburgh (TNO), Andreas Stordal (IRIS, International Research Institute of Stavanger, Norway), Paul Van den Hof (TU Eindhoven/TU Delft), Jan Dirk Jansen (TU Delft):
Robust ensemble-based multi-objective optimization and insights into the objective function search space

The true geology of a hydrocarbon reservoir is never known with certainty, and production optimization of a single geological model, whether single- or multi-objective, may therefore lead to inaccurate results. One method of including geological uncertainties is by optimizing over an ensemble of geological realizations. We demonstrate the feasibility to use ensemble-based optimization (EnOpt) for multi-objective optimization under uncertainty. The EnOpt method uses an ensemble of controls, for a given reservoir model, to approximate the gradients of the objective functions with respect to the controls. A major advantage is its independency of the simulation code resulting in simple implementation. If, at the same time, we use different geological realizations for each ensemble member we obtain an efficient technique to perform robust optimization. We tested this approach to perform robust multi-objective optimization using a switching algorithm for combined long-term and short term water flooding optimization. We used a 18553-gridblock reservoir model of a channelized reservoir with 4 producers and 8 injectors. The controls were the flow rates in the injectors, and the long-term and short-term objective functions were undiscounted net present value (NPV) and highly discounted (25%) NPV respectively. We achieved an increase of 16% in the secondary objective for a minimal decrease of 0.3% in the primary objective, as averaged over 100 geological realizations. The total number of reservoir simulations was around 10000, which indicates the potential to use the method for robust multi-objective optimization of medium-sized reservoir models.
Subsequently, we found that results achieved by primary objective optimized strategy were inferior to a reactive control strategy as averaged over the ensemble which undermines the premise of using optimization. However the result raises a few questions: Is the EnOpt gradient for robust optimization not sufficient ? Or are we just stuck at a local optimum ? The answer to these questions lies in knowing the nature of the objective function space, which in 320 dimensions is practically impossible to visualize. Thus we propose the use of Multi-Dimensional Scaling to plot the nature of the objective function space which gives us insights not only into the quality of the gradient but also confirms the presence of ridges which can be exploited for multi-objective optimization.

9:55 - 10:10 Mohsin Siraj (TU Eindhoven):
A robust hierarchical approach to life-cycle optimization

Model-based optimization of oil production over the life-cycle of an oil reservoir has demonstrated better economic performance but at the same time such optimization suffers from high levels of both economic and modeling (geological) uncertainties. In this talk, I will introduce and highlight the main objectives of my PhD research topics. My research aims to investigate the effect of uncertainties on model-based optimization and to develop novel strategies to reduce the negative effect of uncertainty on production strategies. Hence moving towards robust approaches to life-cycle optimization, where the uncertainty is explicitly or implicitly taken into account in optimization. As a secondary objective of my PhD, I will also briefly discuss the possibilities of data-driven modeling and input-output structural identification in a water flooding process with multiple-inputs (injection wells) and multiple-outputs (production wells).

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10:10 - 10:25 Edwin Insuasty (TU Eindhoven):
Introduction talk and control relevant modeling of oil reservoirs

In this presentation, I will introduce myself and my previous experience in the field of applied mathematics and control theory. In addition I will present part of my kick-off research in control-relevant modeling and uncertain quantification for closed-loop management of oil reservoirs.

10:25 - 11:00 Olwijn Leeuwenburgh, Paul Egberts (TNO), Marcel Alim, Danny Bahagio (TU Delft):
Some new developments in ensemble-based life-cycle optimization

In this presentation two new applications of an ensemble-based gradient estimation technique for life-cycle optimization will be presented. The results originate from two MSc projects conducted at TNO and in part at Maersk. The first application is an extension of ensemble-based optimization to a CO2 WAG case. Both injection rate or pressure and duration (i.e. slug length) were optimized by introduction of rate (or pressure) and switching time as control types. An application to a real field case using only injection pressure as controls for individual slugs showed that improvements can be gained relative to a constant strategy. Further optimization of switching times showed significant additional potential in a small synthetic case.
In the second part of the presentation we first will review current approaches to deal with constraints in life-cycle optimization. We will then introduce a new approach based on the ensemble framework and present a few examples of this approach on a small synthetic reservoir case. Both input and output constraint handling will be discussed.

11:00 - 11:30 ***Coffee/tea break***

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11:30 - 12:05 Ernesto Della Rossa, Laura Dovera (ENI):
Data assimilation and ensemble optimization: real experiences and open issues

The maturity of ensemble techniques in reservoir studies is demonstrated by real cases applications on data assimilation and reservoir life cycle optimization. At the same time the continuous use of these methodologies raise some issues and criticalities that still need to be further investigated and solved.
The objective of the presentation is a short survey of some real field applications of ensemble methods with a review of specific open issues. Firstly a problem of assisted history matching with a complex geological workflow for uncertainty modelling is shown, followed by a description of a joint geodetical and dynamical data assimilation case. A third problem of polymer flooding optimization is then presented with a focus on robust optimization on a set of alternative matched models. The two last cases are introduced with the objective to cast a glance at the ensemble based waterflooding optimization problem with a preliminary comparison between adjoint based and ensemble based optimization. The closing part of the presentation is dedicated to a tough data assimilation problem and the corresponding optimization with complex modelling of well controls.

12:05 - 12:30 Eduardo Barros (TU Delft):
Value of information in closed-loop reservoir management

This presentation addresses a value of information (VOI) analysis for a reservoir toy model with uncertain parameters. The focus of this analysis is on the value of measurements of oil and water rates available during the producing life of the reservoir. The objective is to identify at which moment and with which precision this data would be most valuable within a reservoir management context, so that the best measurement strategy can be defined during the design phase, before starting operating the field. The VOI calculation makes use of a decision-analysis framework, supported by tools such as robust optimization and data assimilation.

12:30 - 12:55 Siavash Kahrobaei (TU Delft), Gerard Joosten (Shell), Malgorzata Kaleta (Shell), Paul Van den Hof (TU Delft/TU Eindhoven), Jan Dirk Jansen (TU Delft):
Hidden information in ill-posed inverse problems

It is well known that parameter updating of large scale numerical reservoir flow models (a.k.a. 'computer assisted history matching') is an ill-posed inverse problem. Typically the uncertain parameters in a reservoir flow model is very large whereas the available information for estimating these parameters is typically limited. Consequently there is never enough information to resolve all the uncertain parameters. The classic solution to this problem is to regularize the unknowns. This is can done by e.g. penalizing deviations of a prior model. Nevertheless penalizing deviations from prior permeability and porosity fields (in a Bayesian setting) usually leads to updated parameter values that are very close to the prior model. Attempts to estimate all uncertain parameters from production data without regularization typically lead to unrealistically high parameter values and therefore to updated parameter fields that have little or no geological realism. However, it can be shown that sometimes the application of unregularized reservoir parameter estimation still appears to have added value.

12:55 - 14:00 ***Lunch in the Exhibition room***

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14:00 - 14:35 Gijs van Essen (Shell):
AHM in practice: the challenge of matching water measurements

Watercut measurements provide very useful information about connectivity within the reservoir. Especially in waterflooded fields with many wells, subsurface uncertainty can be reduced significantly by honoring these data through history matching. The adjoint functionality has proven to be a very efficient technique in (computer-) assisted history matching (AHM) of historical production data. In Shell, adjoint-based AHM has been applied successfully in practice on a large number of fields. However, in a few cases the adjoint failed to improve the match on historical watercut measurements. In this presentation, the circumstances under which adjoint-based AHM of water measurements is unsuccessful are discussed. In addition, a practical approach is presented to circumvent this issue. This approach has been applied successfully to the model of a mature onshore field with a large number of wells, improving the well-by-well watercut match considerably.

14:35 - 15:00 Slawomir Szklarz, Marielba Rojas (TU Delft):
POD-DEIM reduced reservoir simulation

Model order reduction techniques are useful for decreasing the computational cost associated with high-dimensional and complex dynamical systems, such as reservoir models. The Proper Orthogonal Decomposition (POD) is one of the most popular model order reduction methods for nonlinear systems. POD relies on snapshots of the state at different time steps in order to linearly transform it into a coordinate system of lower dimension that captures the largest variance in the data. Note that in POD reduced models, nonlinear terms are evaluated at vectors of the original (large) dimension. Thus, the complexity remains the same. The recently-proposed Discrete Empirical Interpolation Method (DEIM) is an extension of POD that aims to overcome this disadvantage. We are currently investigating the use of DEIM for model reduction of reservoir models. We will discuss implementation issues and describe some features of the POD-DEIM reduced models within a Matlab simulator, using a simple model as illustration.

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15:00 - 15:25 Tudor Popa (TU Delft):
History matching exercise for the Norne field

The number of applications of ensemble-based methods for history matching of field cases is extremely limited. In most published filed cases where the Ensemble Kalman Filter (EnKF) or its variation are used, the application is a reduced synthetic case with a small number of wells, which doesn't reproduce the complexity of a real field case and challenges encountered when a successful history match is the final goal.
In this work, we compare the application of few ensemble smoothers (ES-MDA, ES, and LM - ES) to the history matching of the Norne field, a North Sea field, with a moderately large number of wells and a relatively long production history. A key issue in any history matching is the quality of the initial ensemble and its capability to span the observations/measurements space. This will be our first task in hand. We also discuss the challenges encountered in using ensemble-based method for complex field case studies that are not typically encountered in synthetic cases.
The Norne Field produces from an oil and gas reservoir discovered in 1991 offshore Norway. The full field model consists of four main fault blocks that are in partial communication and many internal faults with uncertain connectivity in each fault block. There have been 22 producers and 9 injectors in the field. Production rates of oil, gas and water of 22 producers from 1997 to 2006 and RFT pressure from 14 different wells are available for model calibration. The total number of active cell is about 45,000.
The Levenberg-Marquardt form of the iterative ensemble smoother (LM-EnRML), the Ensemble Smoother with multiple data assimilation (ES-MDA) and the traditional Ensemble Smoother (ES) are used for history matching the Norne full field model using production data and RFT pressure. The model parameters that are updated include permeability, porosity and net-to-gross ratio at each gridblock, vertical transmissibility at each gridblock for six layers, transmissibility multipliers of 53 faults, end-point water and gas relative permeability of four different reservoir zones, depth of water-oil contacts and transmissibility multipliers between a few main fault blocks. As in any real field case application the need for localization is proven. Engineering experience based localization is implemented and compared with an adaptive localization in order to regularize the updates from the smoothers.

15:25 - 15:30 Dries Hegen (TNO):
Closing remarks

15:30 ***Drinks in the Exhibition room***

16:00 Steering Committee Meeting (room 03.270)