REAL TIME PRODUCTION MANAGEMENT (RTPM) OF PETROLEUM RESERVOIRS

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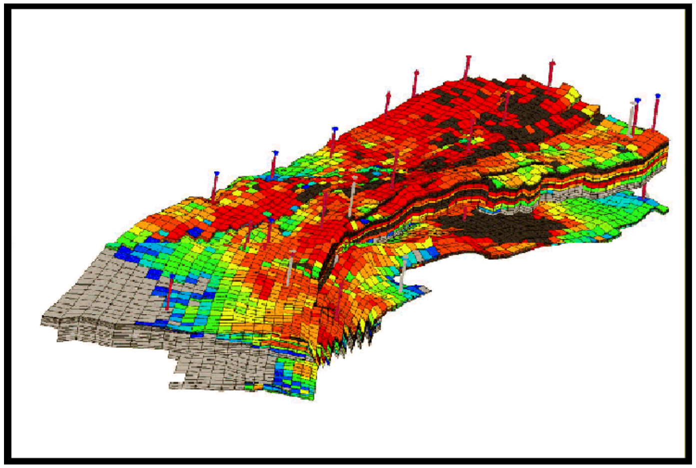


Enterprise-Wide Optimization Meeting

March 13 2013

Motivation

❑ Need for better utilization of resources

- Increasing need for fossil fuels (Van Doren 2010)
- Decreasing petroleum production (Van Doren 2010)
- 40% of expert workforce will retire in the current decade (Parry et al. 2006)
- In the order of US$500B could be saved by better operation of the North Sea oil fields on Norwegian shelf alone (PETORO estimation, 2007)

❑ Significant potentials to provide decision support and improve the performance of oil production

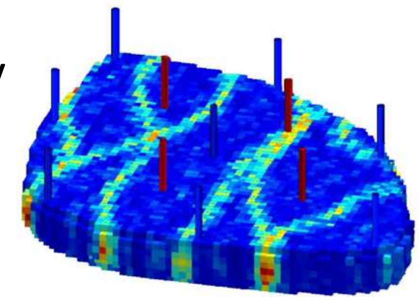
- Advanced instrumentation and control technologies (Hardware and Software)
- Production and Seismic Data
- Geological Models and Process Simulators

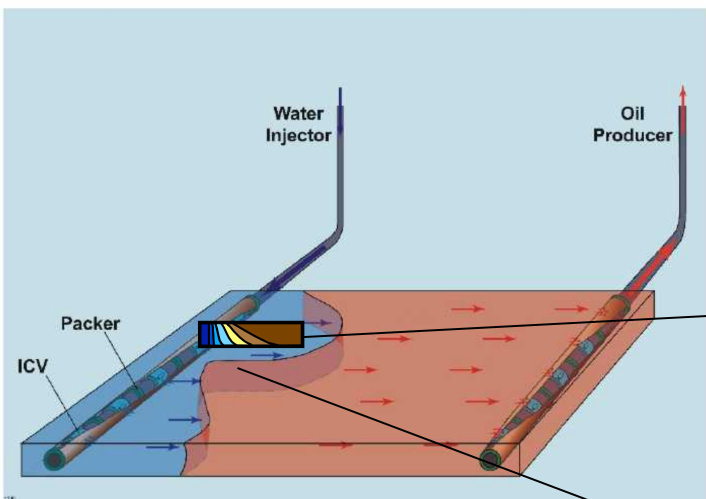
<u>Objective:</u> Closed-loop reservoir operation management

- To develop strategies to improve the oil recovery process by closed loop operation and optimization of the water flooding in a mature oil field.

Water Flooding For Enhanced Oil Recovery (EOR)

- To maintain the pressure of the reservoir and maximize recovery
- Water fills the void created by the produced oil and pushes the oil towards production wells

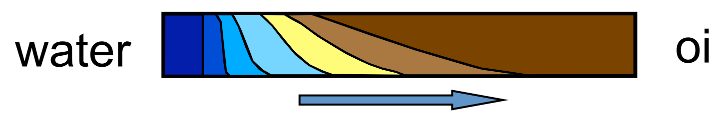




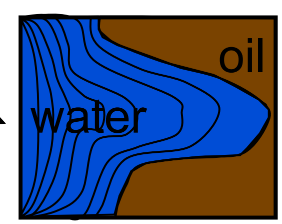
Source: [Brouwer 2004]

Reservoir dynamics show two "coupled" effects:
(Brouwer 2004)

1) **Diffusive characteristics:**
   Pressure driven flow



2) **Convective characteristics:**
   Saturation dependent flow/permeabilities



Problem Statement

Objective: Real-Time oil production management from a reservoir under water flooding to achieve the following goals:

- **Maximize the oil production**
- **Minimize the oil production time**
- **Avoid problems such as fingering in the water flooding process**

Expected outcome

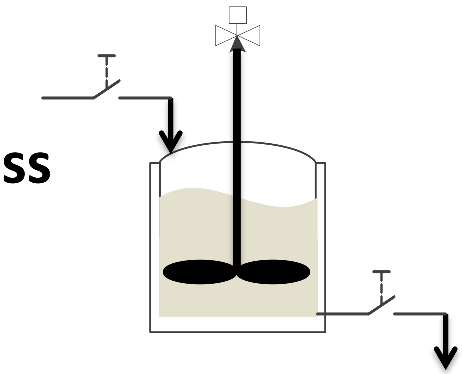
✓ **10 % increase in total oil recovery through optimization and control**

Progress by ICP

- A detailed reservoir model is developed based on the ECLIPSE 100.
- ECLIPSE model is fitted to the historical field data (1943-2009).
- ECLIPSE Simulator will be considered as the process for data generation.
- ACTNUM function in ECLIPSE is used to extract a reduced model by eliminating inactive cells.
  - The reduced model is validated by ECLIPSE (~ 3 times faster simulation than original model)
- A closed-loop reservoir pilot is prepared to evaluate the results of the studies.
- A MATLAB toolbox is under development to represent the ACTNUM model

Different Levels of Control in the Process

The reservoir under production is a Semi-Batch process



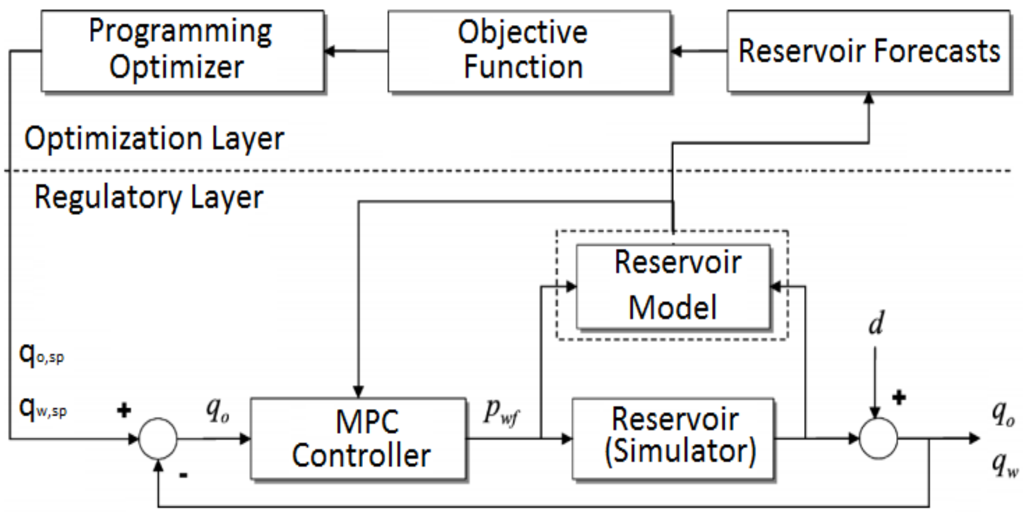
- **Real-Time Optimization (RTO) to determine/update the trajectories (Supervisory Level Control)**
  - To maximize the production while minimizing the production time
  - Respect process and control constraints

- **Adaptive Models Predictive Control (AMPC) (Regulatory Level Control)**
  - Make the process variables follow their specified trajectory
  - Reject disturbances

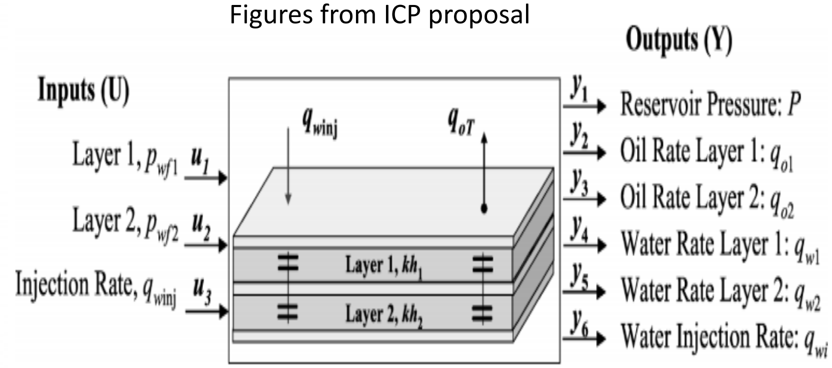
Proposed Solution

- Develop a data-driven model based on the simulated data from ECLIPSE
  - POD, Subspace Identification, reduced-order model by Hankel transform
- Adapt the model to process data
  - ECLIPSE Simulated Data or Pilot Field Data
- Regulatory control: Design an adaptive MPC based on the model
  - Time scales:
    - Sample time: 1 week
    - Prediction horizon: 10 weeks
    - Control Horizon: ≤10 weeks
- Supervisory Control: Long term optimization to update trajectories
  - Over a long horizon, e.g. entire life of the reservoir or 10 years
  - Frequency: 1 per year

RTPM Framework



Figures from ICP proposal



Critical input variables	Measured Output Variables	Key Performance Indicators
Injection rate in Layer i Pressure in Layer i	Oil production, Layer i Gas production, Layer i Water rate, in Layer i Reservoir, Pressure	Water saturation Water front Total production Cost of operation

Challenges:

- High dimensional process with complex process model
- Developing accurate reduced order models
- Uncertainty and identifiability(very few and far between measurements)
- Continuously time-varying process
- Optimization with uncertainty for long term operation

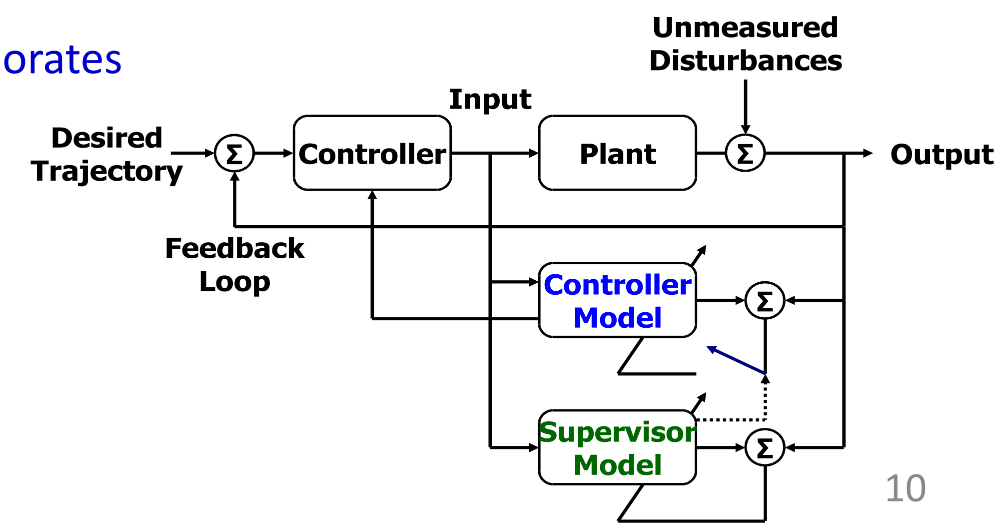
Modeling

- ❑ **Simulated data from ECLIPSE satisfying Identifiability conditions**
- ❑ **Different system identification techniques will be evaluated:**
  - **SIMs and LVMs** (Shi and MacGregor 2001)**:**
    - ☑ Easy to develop (no NLP for parameter estimation, no iterative identification)
    - ☑ Easily handle MIMO processes
    - ☑ Use the POD concept to develop reduced-dimension models
    - ☑ Different data arrangement from conventional system identification techniques
  - **LVMs**
    - ☑ No complication/bias in parameter estimation
    - ✖ Non-causal model structure: not easy to validate and analyze
    - ✖ Non-parsimonious Model
  - **SIMs:**
    - ☑ Causal model (state Space format)
    - ☑ Parsimonious Model (smooth prediction)
    - ✖ Difficult to avoid model bias (should be handled my adaptive techniques)
- ❑ **Other possibilities:**
  - – Hankel transform (Van Doren 2010)
  - – Model-free SIM (Favoreel et al. 1999)

Robust Model Adaptation

- **Model development and maintenance poses a major challenge in applying MPC to industrial processes.**
- **Adapting model to any real-time data is more likely to deteriorate the model**
  - Noise effects
  - Different operation mode effects (even operator interferences)
- **data screening and reconciliation should be considered to enhance the fidelity of the data**
- **A supervised approach is used for model adaptation**

  (Dozal-Maejorada & Ydstie, 2007-2008)
  - Adaptation when prediction deteriorates
  - Constrained parameter estimation



Real Time Optimization (Supervisory Level Control)

Long-term Optimization

$$\max J = \sum_{k=0}^{p-1} \sum_{n=1}^{N_{pr}} \sum_{i}^{N_{seg}} q_{o,n,i}^{2}(k)$$

- P is the prediction horizon, N_{pr} is the number of producer wells, N_{seg} is the number of considered layers and q_o is the oil production rate.
- Optimization will be used to update the setpoint trajectories for the lower level controller (AMPC)
- Challenges:
  - Continuously time-varying process (if use multiple models, they need to be coordinated)
  - Optimization size
  - Possibility of using Latent Variable Models for batch process optimization (Flores Cerrillo and MacGregor 2004)

Increasing the simulation time by Projective Integration

(Kevrekidis and Samaey 2009)

- Inner integration at small time steps to damp out fast dynamics
- extrapolation over a large number of time steps for the slow dynamics
- Suitable for Stiff differential equations and stochastic simulation

Summary and Project Outlook

- **Closed-loop reservoir management**
  - Problem is defined
  - The general framework is determined
  - Trajectory tracking control will be based on robustly adapted linear models
  - Optimization problem poses a challenge
  - Modeling and system identification will play a central role in this project
- **Will be completed over 3 years**
  - Technical development for closed loop operation and optimization of water flooding in 2013.
  - The implementation of optimal control strategy in simulation and real tests on the Yarigui-Cantagallo pilot field in 2014
  - Developing the strategy and software for company-wide implementation in 2014-2015
- **Previous experiences at CAPD will support the project** (Ydstie & Jiao, 2006)