THE COMPLETE, UP-TO-DATE, Practical Guide to Modern Petroleum Reservoir Engineering

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Advances in Reservoir Management Technologies

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Advances in Reservoir Management Technologies
Presentation Outline

• Introduction of Topic
• The Five Major Areas of Technology Advances
• Reservoir Management Principles Matched to Reservoir Management Technologies
• An Intelligent Field Example in Angola
• Quantified Benefits of Intelligent Fields from Three Companies
• Closing Remarks
Advances in Reservoir Management Technologies
Definitions of Smart/Intelligent Wells and Intelligent Fields

• Smart/Intelligent wells are defined as wells which are equipped with devices that enable remote monitoring, control, and transmission of data from multiple zones thereby providing capabilities to optimize production, improve reservoir management, and reduce intervention costs.

• Intelligent fields are defined as fields that have centralized monitoring, control and management of smart/intelligent wells with the objective of implementing and executing defined reservoir management strategies.

References: SPE 88505, 134934, & OTC 17999
Advances in Reservoir Management Technologies
Five Major Areas of Technology Advances

• Major technological advances in reservoir management can be grouped under five areas:
  – Down-Hole Sensors (DHS)
  – Down-hole Control Devices (DCD)
  – Well Architecture
  – Field-wide Monitoring
  – Data Acquisition, Transmission, and Utilization
Advances in Reservoir Management Technologies
Down-Hole Sensors (DHS)

• DHS are devices installed to monitor, measure, and transmit data on fluid flow, fluid properties, and other well performance data.

• DHS include permanent pressure and temperature gauges, distributed temperature and pressure sensors, sand production sensors, seismic sensors, and single/multiphase flow meters.
Down-hole Sensors
Applications: Permanent Down-hole Gauges (PDG)

• The most popular DHS used around the world is permanent down-hole gauges (PDG) with more than 10,000 units installed worldwide.

• Some reservoir management applications of PDG:
  – Measurement of static and flowing reservoir pressures
  – Replacement of shut-in tests
  – Monitoring of interference tests
  – Reservoir voidage control
  – Modeling of inflow performance
  – History matching well and reservoir performance

References: SPE 87681-PA, SPE 103513, SPE 107268-PA
Down-hole Sensors
Applications: Optical Flow Meters

- Optical flow meters can be configured as a single-phase or a multiphase flow meter. Optical flow meters provide long term stability, high reliability, offer full through-bore access, with no permanent pressure drop along its length.

Reference: SPE 99696
Down-hole Sensors
Applications: Physical Multiphase Flow Meter

- Measurement principle combines Venturi and Dual Energy Gamma fraction measurements:
  - Venturi flow is used for mass flow rate measurement
  - Dual energy gamma meter is used for measurement of oil, water, and gas fractions

Reference: SPE 128542

Multiphase flow meter- FRAMO Engineering AS
Down-hole Sensors
Benefits of Single/Multiphase Flow Meters

• They replace conventional separator systems for measurements of oil, water, and gas flow rates.

• Down-hole multiphase flow meters can achieve significant cost savings in capital and operating expenditures especially in offshore installations by:
  – Eliminating the need for test lines, test separators, and manifolds.
  – Reducing space requirements on platforms and FPSO.
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Down-hole Control Devices (DCD)

- DCD are used to regulate specific interval of a well to achieve zonal control of inflow or outflow of fluids without need for remedial intervention.

- The two main types of DCD are interval control valves (ICV) and inflow control devices (ICD).
Down-hole Control Devices (DCD)
Applications: Interval Control Valves (ICV)

- In an application shown in the diagram below, packers and ICVs are used to isolate production from two laterals and the motherbore in a multilateral well.

References: SPE 105141, SPE 126089
Down-hole Control Devices (DCD)  
Applications: Auto-Gas Lift (AGL)

- Auto-Gas Lift (AGL) is applied by using gas in the gas cap or adjacent gas interval to lift fluids from an oil interval thereby eliminating the need for surface facilities. The advantages of AGL include: Reductions in capital costs, operating costs, and well intervention costs.

References: OTC 20123, OTC 21063, SPE 81107
Down-hole Control Devices (DCD)
Applications of Interval Control Valves (ICV)

• Other applications of ICVs include:
  – High pressure variation between laterals or well segments.
  – Large differences in productivities between laterals.
  – Presence of fractures, faults, and high permeability intervals.
  – Varying GOR/WOR between laterals or well segments.
Down-hole Control Devices (DCD)

Applications: Inflow Control Devices (ICD)

- ICDs have been used extensively in horizontal wells in Saudi Arabia. The growth of ICDs in Saudi Arabia is shown in the top right figure.

- The main benefit of using ICDs is to manage uniform flow distribution along horizontal section of the wellbore as shown in bottom right figure.

Reference: OTC 20123
Down-hole Control Devices (DCD)  
Applications of Inflow Control Devices (ICD)

• Other applications of ICDs are to:
  – Reduce coning or cusping effects.
  – Delay early water or gas breakthrough.
  – Reduce production losses.
  – Prolong the productive lives of horizontal wells.
  – Reduce the adverse effects of frictional losses due to high flow rates.
Advances in Reservoir Management Technologies
Well Architecture

• Advances in drilling, geosteering, and completion technologies have led to the development of wells with complex architecture.

• Long reach horizontal wells and multilateral wells are commonly used to improve hydrocarbon recovery from many onshore and offshore reservoirs.

• Multilateral well performance can be predicted reliably with:
  – Semianalytical models; Babu and Odeh (1989), Ouyang and Aziz (2001)
  – Point Source Models; Ouyang and Aziz (2001)
  – Reservoir Simulation models- Many commercial simulators have capabilities to model multilateral wells

Reference: SPE 81107-PA
Well Architecture – Multilateral Wells
Application: Stacked Laterals in a Layered Reservoir
Well Architecture
Application: Improvements in Reservoir Contact Area

- Advances in the drilling of long reach horizontal wells and multilateral wells have improved significantly the area of the reservoir that is drained.
- This is reflected in the results achieved in Saudi Arabia with maximum reservoir contact (MRC) wells. As the top figure shows, the productivity indices of wells have increased with increase in reservoir contact areas.
- The bottom figure also shows the costs of MRC wells have declined with increase in reservoir contact areas.

Reference: SPE 88986
Advances in Reservoir Management Technologies
Field-wide Monitoring

- Field-wide monitoring of reservoir performance has advanced with the application of 4D seismic surveys.

- 4D seismic technology is a low risk, high benefit reservoir management tool.

- 4D seismic technology can be used to:
  - Identify interwell movement and position of reservoir fluids
  - Locate untapped and bypassed oil
  - Allocate and target injection fluids
  - Avoid premature gas or water breakthrough
  - Optimize location of infill wells
  - Maximize economic hydrocarbon recovery

Reference: OTC 8289, SPE 65369, SPE 128542
Advances in Reservoir Management Technologies
Data Acquisition, Transmission, and Utilization

• Advances in these reservoir management technologies have created huge reservoir performance data that must be transmitted, stored, analyzed, integrated, and utilized for near real-time reservoir management.

• Near real-time reservoir management has created an advanced reservoir management process described as closed-loop reservoir management. In a close-loop reservoir management process, real-time data are used to optimize production from the reservoir in near real-time.

References: SPE 112205, OTC 18744
Data Acquisition, Assimilation, and Utilization
Elements of Closed-Loop Reservoir Management Process

References: SPE 99696, SPE 119098
Future Advances in Reservoir Management Technologies

• Future areas of advances include:
  – Intelligent fields that adjust down-hole conditions based on criteria determined in a closed-loop reservoir management system with little or no human intervention.
  – Electromagnetic Imaging (EM)*: Using low-frequency EM signals to distinguish between salty water and oil in a reservoir.
  – Gravity Measurement*: Devices to measure oil distribution in the reservoir based on ability to distinguish between oil and water due to differences in densities.
  – Nanotechnology*: These are ultra small particles capable of moving through the connected pore spaces in a reservoir and performing tasks such as tracing water flow paths or delivering chemicals where needed.

* JPT, June 2012
Five Principles of Reservoir Management
Matched to Advanced Management Technologies

- The five principles of reservoir management:
  - Conservation of reservoir energy
  - Early application of simple strategies
  - Sustained and systematic collection of data
  - Implementation of improved technologies
  - Long term retention of staff in a multi-disciplinary team

Reference: Petroleum Reservoir Engineering Practice by Dr. Nnaemeka Ezekwe, 2011
Matching Reservoir Management Principles to Reservoir Management Technologies

1. Conserve reservoir energy
2. Early application of simple strategies

• Downhole control devices (DCD) have revolutionized ability to conserve reservoir energy and apply simple reservoir management strategies:
  – DCD are used in many reservoirs to reduce production of free gas thereby conserving reservoir energy.
  – Interval control valves (ICV) are widely used to inject water into specific intervals for pressure maintenance and waterflooding.

Reference: Petroleum Reservoir Engineering Practice by Dr. Nnaemeka Ezekwe, 2011
Matching Reservoir Management Principles to Reservoir Management Technologies

3. Sustained and systematic collection of data

- Down-hole sensors have greatly increased our ability to collect large quantities of data from wells by using permanent downhole gauges, multiphase flow meters, and other downhole sensors.

- These data are better in quality and utility than previously available from surface-based devices.

Reference: Petroleum Reservoir Engineering Practice by Dr. Nnaemeka Ezekwe, 2011
Matching Reservoir Management Principles to Reservoir Management Technologies

4. Implementation of improved technologies
5. Multi-disciplinary teams

- Multilateral wells are being used around the world to improve productivity.
- Many companies have formed collaboration teams for management of intelligent fields in near real time.

Reference: Petroleum Reservoir Engineering Practice by Dr. Nnaemeka Ezekwe, 2011
Intelligent Field Example: Greater Plutonio Field, Angola
Field Development Layout

- 5 fields with multiple stacked reservoirs
- 5 year continuous drilling program with 1 rig
- 43 wells (20 producers, 23 injectors)
- 9 producers / 2 gas injectors / 6 water injectors at start-up

Reference: SPE 128542
Greater Plutonio Field, Angola
Field Summary

• Consists of 5 fields (Plutonio, Cobalto, Galio, Cromio, and Paladio) in 1200-1400 meters of water depth.
• Development is 100% subsea with a large FPSO.
• At start-up in 2007, 9 producers, 6 water injectors, & 2 gas injectors were online.
• Production reached 200,000 bpd after 3 months from start-up. 300 mmcfpd of gas injection & 300,000 bpd of water injection were achieved within 12 months of start-up.
• This field is operated as one of BP’s Field of the Future* flagship using advanced reservoir management technologies.

Reference: SPE 128542

* BP Trade Mark
Reservoir Management Technologies Used in Greater Plutonio Field

Down-Hole Sensors (DHS)

• Permanent down-hole pressure/temperature gauges installed in all wells.
• Multiphase flow meters are used for well testing.
• Acoustic sand detectors used in all open-hole gravel pack completions.
Picture of Multiphase Flow Meters Used in Greater Plutonio Field

Reference: SPE 128542
Reservoir Management Technologies Used in Greater Plutonio Field
Down-hole Control Devices (DCD)

- Interval control valves (ICV) on water injectors are used to direct injection into specific zones.
  - CAPEX reduction was achieved by reducing number of water injectors needed in the project.

- The reservoir management strategy implemented in this field is full pressure maintenance by balancing voidage. This is achieved by directing injection to specific zones with fewer wells.

Reference: SPE 128542
Reservoir Management Technologies Used in Greater Plutonio Field
Field-wide Monitoring with 4D Seismic Data

- 4D Seismic data acquisition:
  - Baseline survey conducted in 2000
  - Monitor 1 survey completed in 2009
  - Monitor 2 survey completed in 2011
  - Monitor 3 survey planned in 2013

- Difference maps and volumes from 4D seismic data have been used to locate infill wells, simulate reservoir performance, and modify reservoir management strategies.

- 4D seismic data have been used to identify advancing water front in the Galio reservoir and shrinking gas cap in the Plutonio reservoir.

- Optimized relocation of new wells from these observations have delivered in excess of **13.7 MMBO**.
Greater Plutonio: Galio Reservoir
4D Response Showing Advancing Waterfront
Greater Plutonio: Plutonio Reservoir
4D Response Showing Shrinking Gas Cap
Reservoir Management Technologies Used in Greater Plutonio Field
Data Acquisition, Transmission, and Utilization

- Data transmission through communication infrastructure that includes: downhole cables, subsea cables, onshore broadband, satellites, etc.
- Real time data processed using ISIS (Integrated Surveillance Information System, proprietary BP software)
- Engineers have access to key production data in near real time irrespective of location
- Well and facilities intervention measures are initiated based on near real time data
BP: Field of the Future* Program
Quantified Benefits of Intelligent Fields

- Field of the Future technology is deployed in all top producing regions
- Eighty percent (80%) of the top 100 wells in BP use Field of the Future Technology. These top 100 wells produce 40% of total BP production worldwide.
- Evaluation of program in 2011 showed that Field of the Future technologies improved production by 73,000 BOEPD in BP producing assets.
- By end of 2020, new target is to improve production by 200,000 BOEPD in BP by applying Field of the Future technologies in key producing BP assets.

Reference: SPE 106859, SPE 122676-PA, SPE 150173
SHELL-’Smart Fields’ Program
Quantified Benefits of Intelligent Fields

- SHELL started their ‘Smart Fields’ Programme in 2002.
- Total quantified benefits from 2002-2009 were reported to be $5 billion. SHELL reported benefits from intelligent field technologies in the following categories:
  - About 70,000 BOPD additional production
  - Total CAPEX reduction of $800 million
  - Recurring OPEX reduction
  - Health, Safety, & Environment (HSE) benefits achieved but not assessed
  - Increment in ultimate recovery present but not included in reported benefits

Reference: SPE 128245
Woodside Energy: Intelligent Fields Management
Cossack-Wanaea-Lambert-Hermes Field, W. Australia

- CWLH are 4 oil fields with 11 subsea wells tied back to an FPSO. Production started between 1995 and 1999.
- Intelligent Fields Management (IFM) was installed in 12 months in 2007 with off-the-shelf technology and little prior knowledge by Woodside Energy.
- Reasons to implement IFM technology in CWLH Field include:
  - Significant production deferral due to well testing
  - Increasing water production
  - Limited availability of gas for gas lift operations
- Key commercial software bought off-the-shelf are:
  - Petroleum Experts’ Integrated Field Manager*
  - ISS Group’s Babelfish*
- Results of IFM program in CWLH Field
  - Less well tests
  - Better efficiency and trouble shooting
  - Integrated data analyses
- Reported benefits of IFM program in CWLH Field
  - Integration of data and work practices
  - Better management of operations, wells, and facilities
  - Reduced downtime for wells
  - Woodside Energy estimates the benefit-cost ratio of IFM at 10 t0 1

Reference: SPE 116519

* Trade Mark
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Closing Remarks

• Down-hole sensors, Down-hole control devices, Multilateral wells, 4D Seismic, and Integrated field management software have revolutionized field operations and reservoir management. The oil fields of the future is being installed right now!

• For everyone present here today, the key lesson to take away is that these technologies are available and should be considered for installation in new ‘green’ fields and old ‘brown’ fields as reliable, proven technologies for saving costs and improving reservoir management. The key question now is: WHY NOT USE THESE TECHNOLOGIES TO MANAGE YOUR RESERVOIRS AND FIELDS BETTER?
Advances in Reservoir Management Technologies

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