Development of Donghae-1 Gas Field, Offshore Korea

30 March 2004
KIGAM (Korea Institute of Geoscience & Mineral Resources)
KNOC (Korea National Oil Corporation)

The 3rd Workshop of the Cambodia PPM Case Study
Donghae-1 Gas Field

Reservoir Location

Water Depth
Distance from Shore

Sectional View
DEVELOPMENT OF DONGHAE-1

- Geophysical Prospecting
- Data Processing & Interpretation
- Exploration Well
- Failure
- Location of Appraisal Well Preliminary Feasibility Study
- Appraisal Well
- Reserve Estimation
- Feasibility Study
- Commercial Development
- Economic Feasibility
- Development Options

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Table of Presentation

• Introduction
• Deliverability Analysis
• Development Options
• Compositional Simulation
• Production Optimization
• Production Facilities
• Concluding Remarks
DELIVERABILITY ANALYSIS

DST Data Analysis

- DST & Deliverability Analysis
  - DST Data
  - Reservoir Properties
    - Horner Plot
    - Type Curve Matching
  - Radius of Investigation
  - Wellbore Storage Effect
  - Estimation of Deliverability

<table>
<thead>
<tr>
<th>DST No.</th>
<th>Target Layer</th>
<th>Gauge Depth (ft)</th>
<th>Net Pay Thickness (ft)</th>
<th>Deliverability Test</th>
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</thead>
<tbody>
<tr>
<td>V DST#2</td>
<td>B4</td>
<td>8366.14</td>
<td>103.8</td>
<td></td>
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<td>V DST#3</td>
<td>B2</td>
<td>7685.83</td>
<td>51.7</td>
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<td>V-1 DST#2</td>
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<td>137.4</td>
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<tr>
<td>V-1 DST#3</td>
<td>B2</td>
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<td>48.4</td>
<td>Flow After Flow Test</td>
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<td>V-2 DST#1</td>
<td>B4</td>
<td>8014.07</td>
<td>92.7</td>
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<tr>
<td>V-2 DST#2</td>
<td>B3</td>
<td>7923.85</td>
<td>28.3</td>
<td>Modified Isochronal Test</td>
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<tr>
<td>V-2 DST#3</td>
<td>B2</td>
<td>7843.44</td>
<td>42.3</td>
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</tbody>
</table>
DELIVERABILITY ANALYSIS

Gorae V (DST#2)

DELIVERABILITY TEST

Flow After Flow Test

Actual Data
Stabilized Deliverability Line

$q_{sc} = C(p_R^2 - p_{wf}^2)^n$

DELIVERABILITY TEST

<table>
<thead>
<tr>
<th>Pressure Transient Test</th>
<th>Deliverability Test</th>
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</thead>
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<tr>
<td>$k$ (md)</td>
<td>37.49</td>
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<tr>
<td>$s^*$</td>
<td>4.50</td>
</tr>
<tr>
<td>$p^*$ (psi)</td>
<td>3608.79</td>
</tr>
<tr>
<td>$r_{inv.}$ (ft)</td>
<td>853.92</td>
</tr>
<tr>
<td>$t_{ws}$ (hrs)</td>
<td>0.0021</td>
</tr>
</tbody>
</table>
DELIVERABILITY ANALYSIS

DST Results

- Excellent agreements between *type curve matching method* and *Horner method*
  - Permeability: moderately ranged from 23.0 to 65.3 md
  - Skin factor: 4.64 to 21
  - AOF: 21.2 to 152.8 MMSCFD

- Substantial productivity: more than 60 MMSCFD
  - V-2 (DST #2): 21.2 MMSCFD
DEVELOPMENT OPTIONS

Considerations

• Engineering Data
  ✓ Reserve, Rock and Fluid Properties

• Gas Sales Specifications
  ✓ Marketplace, Supply, Price

• Design Specifications
  ✓ Temperature, Pressure, Processing Capacity of Facilities

• Environmental Data
  ✓ Weather, Subsea Condition

• Economic Parameters
  ✓ Cost of Capital, Operating Expenses
DEVELOPMENT OPTIONS

Selection Process

• 1st Stage: Identification of All Feasible Development Options
  ✓ Substructure System Type
  ✓ Drilling Methods

• 2nd Stage: Selection of Favorable Process
  ✓ Option Screening
  ✓ 24 Production Options

• 3rd Stage: Optimized Development Concept
  ✓ Selection of Preferable Process Option
1) Identification of Development Options

Development Option

- Drilling
  - Permanent Platform Facilities
    - Dry Trees
  - Tender Assist Drilling
    - Dry Trees
  - Mobile Rig Drilled
    - Wet Trees

- Substructure
  - Floating
  - Fixed
  - None
    - Mobile Production Unit
      - Jacket
        - Semi-Submersible
        - FPSO
        - Jack-Up

- Processing & Export
  - All Offshore
  - All Onshore
  - Part Processing Offshore & Onshore
    - Full Processing Offshore
    - Wellstream Transfer to Shore
      - Korean Grid
      - Power Plant
      - Domestic Users

Components
- Strategies
  - Facilities Elements
- Gas Sales Location

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DEVELOPMENT OPTIONS

2) Screening

Brainstorm Exercise

Level 1: Separator, Compression, Dehydration, Dewpointing, Condensate stabilization

Level 2: Position Selection of Each Equipment

Level 3: Optimized Production Process Selection

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Technical Screening

24 Options

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Economic Screening

8 Options

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Selection

8 Options

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DEVELOPMENT OPTIONS

3) Diagram of Preferred Process Scheme

OFFSHORE FACILITIES
- GAS COMPRESSION
- GAS DEHYDRATION
- BULK WATER SEPARATION
- LIQUID DEHYDRATION
- WATER

PIPELINE
- GAS DEWPOINTING
- SLUG CATCHER
- CONDENSATE STABILIZATION

ONSHORE FACILITIES
COMPOSITIONAL SIMULATION

Objectives

• Phase I
  ✓ Estimation of the gas and condensate reserves (GIIP) of Donghae-1 Gas Field

• Phase II
  ✓ To evaluate the field’s development including optimal well locations, various sensitivities and water coning & partially penetrating wells
COMPOSITIONAL SIMULATION

Reservoir Properties

EOS Modeling
- 11 Components (CO2, N2, C1~C6, C7+)
- 5 Pseudo-Components
  (Non-HC, C1, C2/C3, C4/C5, C6+)

Capillary P (Pc) : SCAL

Relative Permeability

Dew-point Phase Diagram

Gas Water Pc

Gas Water kr (Corey Eq.)
COMPOSITIONAL SIMULATION

Model Grid System

- Grid: 47x43x15
- Layers: C1, B1, B2, B3/4
- Constant Thickness

C1: Structure/Isopach/Grid   B1 Reservoir   B2 Reservoir   B3/4 Reservoir
**COMPOSITIONAL SIMULATION**

**Base Case Run**

**Gas & Condensate Production vs. Time**

**Gas & Condensate Rate vs. Cumulative Gas Production**

**Condensate Yield, Water Cut & Average Reservoir Pressure**

**Base Case Results**
- Ultimate Gas Recovery: 142 Bcf (68% of GIIP)
- Period of Production Plateau: 6 years
- Condensate Recovered: 1.2 MMbbl (37% of In-Place)
- Water Production Less Than 1.7 bbl/MMscf
COMPOSITIONAL SIMULATION

Sensitivity Analysis – 13 Cases

- Permeability
  - Production Performance vs. Horizontal Permeability
- Gas Initially In-Place
  - Production Performance vs. GIIP
- Surface Operating Pressure
  - Production Performance vs. FWHP
- Plateau Production Rate
  - Production Performance vs. Field Rate
- Strength of Aquifer
  - Aquifer Strength Sensitivity
  - Effect of Aquifer Strength & Rate on Recovery
- Effect of $k_v$ and Selective Well Completion
COMPOSITIONAL SIMULATION

Compositional Simulation Results

• Probable Reserve of Donghae-1 (Gorae V & V-3 Field):
  - 208 Bcf of Gas, 1.77 MMbbl of Condensate
  - Minimum FWHP of 700 psi & Minimum Allowable Gas Well Rate of 5 MMscf/day Assumed

• 4 Wells Required in the 4 Zones:

• Retrograde Condensation:
  - 2.5 MMbbl of condensate to remain in the reservoir in a liquid state at the end of primary depletion.
  - 1% of HCPV, immobile and no effect on gas deliverability

• Due to the modest k, the Aquifer Strength Weak
  - Insensitive to Plateau Rate, GIIP

• Relatively high k_v/k_h
  - No Effect on the Ultimate Gas Recovery, regardless of penetration
Integrated Network Model

PRODUCTION OPTIMIZATION
**PRODUCTION OPTIMIZATION**

**Integration of Reservoir and Surface Model**

**Compositional Fluid Model**
- Gas-Condensate Flow
- Peng-Robinson Cubic EOS (1976)
- Flash Calculation
- Gas (g) & Condensate (L) Fugacity $f_i$

$$\ln \left( \frac{Z_i}{Z_i^p} \right) = h \frac{Z_i - 1}{b} - \ln (Z_i - B) - \frac{A}{2.82843B} \left[ \frac{2\Psi - h}{\Psi} \right] \ln \left( \frac{Z_i^p + 2.414B}{Z_i^p - 0.414B} \right)$$

**Subsurface Reservoir Model**
- Multi-Component Tank Model
- Assumptions
  - Homogeneous, Isotropic, Cylindrical Reservoir
  - No-Flow Boundary Condition
  - No Water & Condensate Flow
- Cumulative Gas Production

**Multi-Phase Pipeline Flow Model**
- Vertical Pipeline (Production Well) – PIPESIM
- Horizontal Pipeline – Multiphase Flow Model
- Vertical & Horizontal Flow Patterns

**Pipeline Network Model**
- PIPESIM (Build 26, 1999)
- Transport Pipeline, Production Line, Riser
- Branch System
- Modeling of Separator, Pump, Compressor
**Production Optimization**

**Production Allocation & Compressor Installation**

- **Allocation of Gas Production**

- **Pressure Profile at Separator**

- **Cum. Gas Production at Separator**

- **Cum. Condensate Pro. at Separator**

**Production Scenario**
- Total Production Rate: 50 MMscf/D
- BD12, BD13 Line: Detour Line for Emergency
- Platform Minimum Pressure: 500 psia
- Allocation of Optimized Gas Production Rate

**Optimized Production Rate**
- Plateau Period: 3900 Days
- Compressor Installation: 2000 Days (5.5 yrs)
- Cumulative Gas Production (During Plateau Period)
- Cum. Condensate Pro. (During Plateau Period)
PRODUCTION FACILITIES

- Subsea Production Facilities
- Offshore Production Facilities
- Pipeline
- Onshore Structures
CONCLUDING REMARKS

- Donghae-1 Gas Field, Offshore Korea
  - Production Options
  - DST
  - Reservoir Simulation
  - Integrated Network Modeling
  - Facility Design

  Gas & Condensate Production (2004)

- We are willing to actively involve in PPM Case Studies: collaborative work with Host Countries
The End
Thank You.