EOR TECHNOLOGIES AND APPLICATIONS IN MALAYSIA

The Petroleum Policy and Management (PPM) Project
4th Workshop of the Indonesia – Kutai Basin Case Study
Jakarta, Indonesia
13 – 17 June 2006

Dr. Nasir Haji Darman
Norhayati Bt Hashim

Presentation Outline

• Introduction
• Current Progress Updates and Status
  • Dulang: Immiscible WAG
  • Baronia: Immiscible Gas Injection
  • West Lutong: Miscible Gas Injection
  • Tapis: Miscible Gas Injection
  • Tabu: Double Displacement
• Issues and Challenges
• Way Forward
• Summary and Conclusions
Custodian of Malaysian Petroleum Resources

Petroleum Management Unit (PMU)

A distinctive resource owner and manager, maximizing value of Malaysia’s hydrocarbon resources

Attract exploration investments
Facilitates development & prod.
Optimize Malaysian E&P Assets
Monitor all E&P companies

To fulfill our role and responsibilities, we must undertake and implement EOR initiatives

PMU Key Business Focus Areas

PMU objective to maximize the domestic long term value of reserves is done through 4 main levers

- Reserves addition: 100% replenishment ratio for crude and 70% for gas through exploration
- Reserves recovery: Additional 33% replenishment ratio through IOR/EOR
- Reserves production: Sustain 3% annual increase in production to meet demand
- Operational excellence: Production enhancement and reliability improvement
EOR in Malaysia: Current Status

We started off with conducting a screening in 2000 & identified 1 Bstb (unrisked) EOR potential

Our progress so far...
- Gas flood – 2 fields at full field WAG implementation, 1 on pilot
- Chemical EOR – pilot for offshore AS flooding
- Total of 11 projects at various stages (from lab study to full field)

Some of our challenges...
- PSC commitment – EOR project payback often after PSC expiry
- Mindset – people view EOR as expensive and difficult
- Gas vs. Oil – EOR will defer gas development (gas cap)

Our target is to add 820 MMstb of reserves from EOR by 2010

EOR in Malaysia: What’s Next?

Integrated CO₂-EOR...
- Why do it
  - Over 18 Tscf HC gas locked due to high CO₂
  - EOR competing for gas with sales gas/LNG
  - CO₂ perform better than natural gas
- CO₂ supply
  - close to 5 Tscf in Peninsular Malaysia
  - over 24 Tscf in Sabah/Sarawak
- EOR target
  - Project A: 9 fields (one area), 150 km from CO₂ source
  - Project B: 2 fields (one area), 140 km from CO₂ source
- EOR process
  - immiscible and miscible
- Status
  - Immiscible pilot started in June-06
  - Miscible pilot decision in final stages

Our next step...
- Phase 2
  - Revisit EOR screening to identify new opportunities
- Partnership
  - Strategic alliances with experience parties to make offshore EOR in Malaysia a reality
As a custodian of Malaysian Petroleum Resources, we have to manage and maximize our hydrocarbon assets.

We have to ensure 520 MMstb of reserves from EOR by 2010 a REALITY

- Re-negotiating our PSC in return for EOR implementation
  - PSC renewal with longer period
  - Better terms

- Tackling Triple Plus
  - Leadership – Formal/Informal coaching, job attachments
  - Mindset – support from the top, show positive results
  - Institutional Capability – succession plan, EOR fraternity

- Revised procedure and guidelines
  - EOR potential is assessed for every green field development
  - IOR and EOR is integrated and not in silos

- Technology Improvement and R&D
  - Supported by UTP, local universities
  - Research Technology Division

Overview of Malaysian Oil and Gas Industry

- Oil was discovered in Malaysia in Miri, Sarawak in 1910.
- Initially producing some 83 barrels per day, the petroleum industry in Malaysia has now grown into a multi-billion dollar business with oil production over 600,000 barrels per day while gas is being produced at 5 billion cubic-feet per day.
- To date a total of 2,664,023 million line km seismic had been acquired and 1,100 exploration wells (515 Appraisal and 585 Wildcat wells) had been drilled in Malaysia resulting in the discovery of a total of 134 oil fields and 178 gas fields.
Overview of Malaysian Oil and Gas Production

Malaysian oil reserves was in declining phase (from 1994 – 2002)
Through a concerted effort, our reserves return to an upward trend from 2003
Our target is to have a minimum of 1.33 replacement ratio
At current rate of production, our reserves life is about 19 years

Current reserves is in plateau stage
Gas supply is critical to PGU and MLNG
Our target is to have a minimum of 0.7 replacement ratio
At current production rate, our reserves life is 33 years

EOR Potential

There is a substantial amount of oil reserves that can be achieved through IOR/EOR processes in the Malaysian oil fields.
Acknowledging the above, PETRONAS has initiated several initiatives to encourage the operators in Malaysia to look into EOR opportunities in their respective operating areas.

Total STOIIP for Malaysian producing fields = 17 B stb

Remaining oil (67%)
EUR (33%)

Source: ARPR 2005
To identify EOR potential, PETRONAS has conducted EOR screening study in year 2000

- Based on the screening study, in Malaysian context, three EOR processes may be considered:
  - Gas injection: miscible or immiscible in WAG or straight mode
  - Chemical methods (surfactant, foam, polymer and gel)
  - Microbial methods.

Systematic approach has been developed to identify EOR potential in Malaysia

- The study screened 31 reservoirs from 16 fields in the Peninsular Malaysia and 39 reservoirs from 19 fields in East Malaysia.
- Considering some practical limitation (such as gas source and reservoir heterogeneity), 37 reservoirs were identified to be technically feasible for IOR/EOR processes.
- Numerical simulation models (sector) were developed for the group which has the highest remaining oil-in-place and the highest recovery for the selected EOR process identified in the first-level screening.
The amount of potential incremental recovery from these reservoirs is almost One (1) Billion barrels

- Sixty percent (60%) of the total EOR potential in Malaysia reside in six reservoirs.

**Presentation Outline**

- Introduction

- **Current Progress Updates and Status**
  - Dulang: Immiscible WAG
  - Baronia: Immiscible Gas Injection
  - West Lutong: Miscible Gas Injection
  - Tapis: Miscible Gas Injection
  - Tabu: Double Displacement

- Issues and Challenges

- Way Forward

- Summary and Conclusions
Phases for EOR implementation: 4 stages with 3 decision gates review

STAGE 1
Screening study
Field and EOR process identification
Preliminary economic assessment

STAGE 2
Detail study i.e. lab and simulation
Pilot design and surveillance
Economic assessment

STAGE 3
Pilot implementation
New data acquisition & processing
Full field design & Economic Assessment

STAGE 4
Full field implementation
Operation, maintenance and surveillance

Gate 1: Viability Approval
Gate 2: Concept Approval
Gate 3: Project Sanction

Stage Activities
Decision Gates
Cost Exposure

Currently we have 11 actively on-going EOR projects in Malaysia

- At different level of maturity. Will discuss the progress of top 5 candidates

<table>
<thead>
<tr>
<th>FIELD</th>
<th>PROCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dulang</td>
<td>Immiscible WAG Injection</td>
</tr>
<tr>
<td>Tabu</td>
<td>Double Displacement</td>
</tr>
<tr>
<td>Baronia</td>
<td>Immiscible WAG Injection</td>
</tr>
<tr>
<td>West Lutong</td>
<td>Miscible Gas Injection</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FIELD</th>
<th>PROCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tapis</td>
<td>Miscible WAG Injection</td>
</tr>
<tr>
<td>Bokor</td>
<td>Aquifer assisted WAG</td>
</tr>
<tr>
<td>CEOR</td>
<td>Chemical Injection</td>
</tr>
<tr>
<td>Tiong/Kepong</td>
<td>Immiscible Gas Injection</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FIELD</th>
<th>PROCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baram</td>
<td>WAG Injection</td>
</tr>
<tr>
<td>GunTong</td>
<td>Miscible WAG Injection</td>
</tr>
<tr>
<td>St. Joseph</td>
<td>Immiscible WAG Injection</td>
</tr>
</tbody>
</table>
Location of the 5 fields

- Three at offshore Peninsular and two at offshore Sarawak

Presentation Outline

- Introduction
- Current Progress Updates and Status
  - Dulang: Immiscible WAG
  - Baronia: Immiscible Gas Injection
  - West Lutong: Miscible Gas Injection
  - Tapis: Miscible Gas Injection
  - Tabu: Double Displacement
- Issues and Challenges
- Way Forward
- Summary and Conclusions
**Dulang field: Background Information**

- One of Malaysia’s major producing oilfield (OIIP =1119 MMstb and EUR = 328 MMstb)
- East-West trending anticline structure dissected by numerous normal faults
- Water depth of 76m and area ~11 km x 3.5 km
- Pilot involves 3 producers and 3 injectors

- Water injection started in 1996 due to falling pressures
- Re-injection of produced gas identified as cost effective EOR option
- Injected gas stream is having more than 50% CO2
- Pilot WAG at S3 block started in Nov-02 targeting E12/13/14 reservoirs

---

**Dulang Field: Immiscible WAG pilot strategy**

**Implementation Strategy**

Components of pilot in S3 block:

1. WAG in non-water invaded area (E12/13/14)
   - Injector: A10
   - Producers: B5 and B16

2. Gas injection (E12/13)
   - Injector: A14 recomplete in E12/13
   - Producer: A2

3. WAG in water invaded area (E12/13/14)
   - Injector: A29
   - Producer: A2

WAG injection (4 MMscf/d gas and 3500 b/d water) for cycles of 3 months each.
**Contributing WAG mechanisms**
- drainage of ‘attic oil’ updip of the existing producers
- more efficient sweep of water flooded regions
- flooding of tighter reservoir intervals
- partial vaporization of the un-swept oil

**Pilot performance**

<table>
<thead>
<tr>
<th>Well</th>
<th>10 BOPD</th>
<th>100 – 300 BOPD</th>
<th>WCUT 95%</th>
<th>70%</th>
<th>Pressure maintained</th>
<th>350 BOPD</th>
<th>600 BOPD</th>
<th>GOR 2000scf</th>
<th>1000scf</th>
<th>1350 psia</th>
<th>1467 psia</th>
<th>105 BOPD</th>
<th>300 BOPD</th>
<th>GOR 4500scf</th>
<th>2200scf</th>
<th>WCUT 80%</th>
<th>70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2L</td>
<td>10 BOPD</td>
<td>100 – 300 BOPD</td>
<td>WCUT 95%</td>
<td>70%</td>
<td>Pressure maintained</td>
<td>350 BOPD</td>
<td>600 BOPD</td>
<td>GOR 2000scf</td>
<td>1000scf</td>
<td>1350 psia</td>
<td>1467 psia</td>
<td>105 BOPD</td>
<td>300 BOPD</td>
<td>GOR 4500scf</td>
<td>2200scf</td>
<td>WCUT 80%</td>
<td>70%</td>
</tr>
<tr>
<td>5L</td>
<td>10 BOPD</td>
<td>100 – 300 BOPD</td>
<td>WCUT 95%</td>
<td>70%</td>
<td>Pressure maintained</td>
<td>350 BOPD</td>
<td>600 BOPD</td>
<td>GOR 2000scf</td>
<td>1000scf</td>
<td>1350 psia</td>
<td>1467 psia</td>
<td>105 BOPD</td>
<td>300 BOPD</td>
<td>GOR 4500scf</td>
<td>2200scf</td>
<td>WCUT 80%</td>
<td>70%</td>
</tr>
<tr>
<td>16</td>
<td>10 BOPD</td>
<td>100 – 300 BOPD</td>
<td>WCUT 95%</td>
<td>70%</td>
<td>Pressure maintained</td>
<td>350 BOPD</td>
<td>600 BOPD</td>
<td>GOR 2000scf</td>
<td>1000scf</td>
<td>1350 psia</td>
<td>1467 psia</td>
<td>105 BOPD</td>
<td>300 BOPD</td>
<td>GOR 4500scf</td>
<td>2200scf</td>
<td>WCUT 80%</td>
<td>70%</td>
</tr>
</tbody>
</table>

**Dulang Field: Plan for full field implementation in 2007**

- Based on pilot performance, results were scale-up to represent full field implementation. P50 of 18.5 MMstb of incremental reserves is expected.
- Acquisition of gas compressor and integration with FFR study is currently on-going

**Dulang Oil Forecast**

**Dulang Decline (2005/6 WP&B)**

**Infill Wells (2004 WP&B)**

- P15 = 23 MMstb
- P50 = 18.5 MMstb
- P85 = 12 MMstb
Presentation Outline

- Introduction

- Current Progress Updates and Status
  - Dulang: Immiscible WAG
  - Baronia: Immiscible Gas Injection
  - West Lutong: Miscible Gas Injection
  - Tapis: Miscible Gas Injection
  - Tabu: Double Displacement

- Issues and Challenges

- Way Forward

- Summary and Conclusions

Baronia Field: Background Information

- 3rd largest producing reservoir in the Baronia field.
- Production started since 1972.
- Initially under-saturated reservoir
- Oil is 42° API and 0.3 cP

- Due to limited aquifer support, peripheral water injection commenced with 4 horizontal injectors in 1994.
- The structure is simple, internally unfaulted, low relief domal anticline. The reservoirs are highly continuous as demonstrated by good geological marker correlation.
**Pilot Objective and Plan**

- Test immiscible gas injection process
- Showcase for a large-scale immiscible gas injection in the BDO fields
- Location: Well BN-29 targeting RV2.1 reservoir

- Gas will be injected from BN-29 at 5 mmscfd
- Continue water injection from BN-58, horizontal injector
- Pilot was designed to provide “least disturbance test” to the current oil production

---

**Baronia Field: Immiscible gas pilot strategy**

- Gas will be injected from BN-29 at 5 mmscfd
- Continue water injection from BN-58, horizontal injector
- Pilot was designed to provide “least disturbance test” to the current oil production

---

**Baronia Field: Plan for pilot project in 2006**

- Model predicted that immiscible gas injection of 5 MMscf/d with continued water injection from next well could yield 2.7 MMstb incremental recovery.
- Pilot FDP has been approved by PETRONAS and flowlines modification is currently underway to convert BN-29 well to become gas injector
- Baronia RV2 immiscible gas injection pilot will be interpreted together with West Lutong miscible pilot (described later) to come out with regional EOR implementation strategy at Baram Delta
Presentation Outline

- Introduction

- **Current Progress Updates and Status**
  - Dulang: Immiscible WAG
  - Baronia: Immiscible Gas Injection
  - **West Lutong**: Miscible Gas Injection
    - Tapis: Miscible Gas Injection
    - Tabu: Double Displacement

- Issues and Challenges
- Way Forward
- Summary and Conclusions

---

West Lutong Field: Background Information

- One of the oldest producing field in Malaysia
- KL and MN reservoirs contribute > 70% of the total production
- 1/3 of the MN commingled modeled as a single unit. STOIP = 110 MMstb

- Pilot to test miscible gas injection in Baram Delta fields
- MMP at or near current reservoir pressure. Strong aquifer.
West Lutong Field: Miscible gas pilot strategy

PILOT PLAN
- 1 injector and 1 observation (100 feet apart)
- Barge mounted CO₂ generator supplying 2 MMscf/d high purity CO₂
- 3 months at 1500 psi injection pressure
- 1st injection anticipated early 2007

PILOT OBJECTIVE
- Determine remaining oil saturation
- Areal sweep efficiency
- Injectivity and need for WAG injection
- Vertical sweep efficiency
- Minimum miscibility pressure

"The West Lutong pilot, if implemented, will become the first miscible pilot in Malaysia. If successful, the miscible process can give an incremental of up to 165 MMstb for the BDO fields."

Both pilots at Baronia and West Lutong are planned to confirm 256 mmstb incremental oil at Baram Delta region (miscible and immiscible processes).
Presentation Outline

• Introduction

• Current Progress Updates and Status
  - Dulang: Immiscible WAG
  - Baronia: Immiscible Gas Injection
  - West Lutong: Miscible Gas Injection
  - Tapis: Miscible Gas Injection
  - Tabu: Double Displacement

• Issues and Challenges

• Way Forward

• Summary and Conclusions

Tapis Field: Background Information

TAPIS EAST-FAULT BLOCK STRUCTURE MAP

• Water depth 64 meters
• Discovered in 1969
• Five platforms
• 90 development wells
• Current focus is on the east fault block of lower J reservoirs

❖ Small gascap is present in the fault block

❖ Lower J unit have contributed some 40% of the total Tapis production.
Tapis Field: Miscible gas study work flow

Tapis EOR study workflow

Element Model

- Select Focus Areas
- Construct Simulation Grid
- Initialize and Calibrate Model
- Run Sensitivity Cases

Scale-up

Full Field Model

- Convert Existing Model to Compositional
- Incorporate EOR Process From Element Model
- Generate Prediction Cases

Tapis EFB Full Field Model

Lower J Unit was selected due to...

- Potential recovery of bypassed and residual oil from mature waterflood
- Large remaining oil remaining in place
- Existing water & gas injection facilities, existing well patterns
- New geologic model and a history matched simulation model available

Process evaluated

- Miscible
- Separator gas
- LPG enrichment

- Immiscible
- CO₂

“The immiscible floods yielded an incremental recovery between 4-7% whereas miscible floods gave a higher recovery between 10-13%.”
Presentation Outline

- Introduction
- **Current Progress Updates and Status**
  - Dulang: Immiscible WAG
  - Baronia: Immiscible Gas Injection
  - West Lutong: Miscible Gas Injection
  - Tapis: Miscible Gas Injection
  - **Tabu**: Double Displacement
- Issues and Challenges
- Way Forward
- Summary and Conclusions

Tabu Field: Background Information

- Oval-shaped east-west trending anticline
- Area = 26 km²
- Water depth = 64 meters
- Two major north-south trending normal faults
- Discovered in 1978
- Developed in 1986

- Study focused on West Fault Block (WFB) in the Upper I reservoirs
- Double displacement process (DDP) is currently being tested
Tabu Field: The double displacement process

- Potential recovery of by-passed oil downdip of high GOR wells by converting alternate wells along periphery of oil rim to water injectors
- The up-dip injector forces the gas cap towards southwest, countering the aquifer influx and increasing future oil from nearby wells.
- Cost of flowlines, well restoration and surveillance is relatively minimal
- Prediction runs showed that DDP for the Tabu WFB Upper I reservoirs alone will give an estimated incremental of 1.8 MMstb
- Field works are currently on-going

Presentation Outline

- Introduction
- Current Progress Updates and Status
  - Dulang: Immiscible WAG
  - Baronia: Immiscible Gas Injection
  - West Lutong: Miscible Gas Injection
  - Tapis: Miscible Gas Injection
  - Tabu: Double Displacement
- Issues and Challenges
- Way Forward
- Summary and Conclusions
Operating EOR in offshore environment is technically challenging

- Only about 9% of world wide EOR application is in offshore environment. On the other hand, all of our producing fields are offshore.
- Some of the most common problem associated with offshore operation
  - Large well spacing
  - Limited space at the surface

![World-wide EOR experiences](source=OGJ 2002)

On average, 68% of the 157 existing platforms installed in Malaysia are more than 20 years old

- Gas injection pipeline, especially with CO₂ handling capability, does not exist. Major infrastructure development is needed (major investment).
- Some of the fields are not reaching the MMP even if 100% purity CO₂ is injected. Major repressurization project for the reservoir is needed before MMP is reached.
- 68% or 157 platforms had been in-placed more than 20 years.

![Age of platform](source=OGJ 2002)
Operating EOR in offshore environment is commercially challenging

- For gas flooding (such as CO2 injection), the average total cost per barrel is around US$ 12 – 20, which, compared to average unit technical cost in Malaysia, is relatively high.

### World wide EOR cost database

<table>
<thead>
<tr>
<th>Process</th>
<th>Cost of Incremental Oil (US$/bbl)</th>
<th>Injectant Only</th>
<th>Total Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam</td>
<td>3 – 5</td>
<td>5 – 7</td>
<td></td>
</tr>
<tr>
<td>Purchased Fuel</td>
<td>4 – 6</td>
<td>7 – 10</td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2</td>
<td>5 – 10</td>
<td>12 – 20</td>
<td></td>
</tr>
<tr>
<td>Chemical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surfactant (Micellar)</td>
<td>10 – 20</td>
<td>20 – 30</td>
<td></td>
</tr>
<tr>
<td>Alkaline</td>
<td>2 – 7</td>
<td>10 – 17</td>
<td></td>
</tr>
<tr>
<td>Surfactant/Alkaline/Polymer</td>
<td>1 – 5</td>
<td>2 – 7</td>
<td></td>
</tr>
<tr>
<td>Polymer</td>
<td></td>
<td>1 – 5</td>
<td>– 2 – 7</td>
</tr>
</tbody>
</table>

Source: SPE 24142

Timing is critical to realise the EOR potential

- A clear and transparent work process must be in place to ensure that all of the requirements for the project assessment are met.
- Long timing leads to unfavorable economics especially to the Contractors. Cut the time required to reach full field application, without cutting any corners ...

**Reservoir Management strategies** based on historical information together with experimental and simulation studies

- EOR Candidate
- Field expansions without a complete interpretation of pilot projects (e.g. Prudhoe Bay)
- Pilot Monitoring
- Successful projects
- Pilot Evaluation
- Large field scale WAG applications
- Surveillance of projects
- Optimization programs

Industry standard

2 – 3 years

3 – 5 years

Source: SPE 50645, 1998
Current mindset and behaviour prohibits EOR potential

- EOR is always associated with uneconomic projects and very difficult to implement, even without study being done.

"The most important reservoir is the reservoir between our ears"
Dr. John Doran, CEO – ROC Oil Company Ltd

Most people in the industry have a disaster mentality about EOR

EOR → Failure → Disaster

Presentation Outline

- Introduction
- EOR Motivations and Focus
- Current Progress Updates and Status
  - Dulang: Immiscible WAG
  - Baronia: Immiscible Gas Injection
  - West Lutong: Miscible Gas Injection
  - Tapis: Miscible Gas Injection
  - Tabu: Double Displacement
- Issues and Challenges
- Way Forward
- Summary and Conclusions
Way Forward

Solution 1
Management support
- clear directions
- conducive environment for EOR
- Strategic and forward thinking

Solution 2
Learning from pilot & other projects worldwide
- balancing risk and benefit
- Take some calculated risks
- effective networking and collaboration effort

Solution 3
Starting early
- EOR need to be considered even during FDP submission for green fields

Solution 4
Synergy in high CO2 gas field development
- long term abundant supply
- facilities sharing by integration

Solution 5
Win-win situation with PS Contractor
- attractive PSC terms
- work commitments
- Focus on REWARD and not COST

Presentation Outline

• Introduction
• EOR Motivations and Focus
• Current Progress Updates and Status
  - Dulang: Immiscible WAG
  - Baronia: Immiscible Gas Injection
  - West Lutong: Miscible Gas Injection
  - Tapis: Miscible Gas Injection
  - Tabu: Double Displacement
• Issues and Challenges
• Way Forward
• Summary and Conclusions
Summary and Conclusions

- There is a substantial amount of oil reserves that can be achieved through EOR process in the Malaysian oil fields.
- Acknowledging the above, PETRONAS has initiated several initiatives to encourage the operators in Malaysia to look into EOR opportunities in their respective operating areas.
- Previously, there were little detailed studies have been conducted to firm up these potentials and monetised them into a full-scale EOR projects.
- Among the main challenges are the operating environment (offshore), maturing assets which require facilities upgrading, limited detailed assessments, and lack of capability were identified.
- In order to meet these challenges, all parties will need to have the right mindset and behaviour towards realising EOR as a real project to increase value in the business.

Thank You For Your Attention