

OVERVIEW OF RESERVOIR SIMULATION AND MODELLING

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Abstract : Reservoir Simulation and Modeling is one of the most powerful tools for guiding reservoir management decisions. From planning early production wells and designing surface facilities to diagnosing problems with enhanced recovery techniques, reservoir simulators allow engineers to predict and visualize fluid flow more efficiently than ever before.

Reservoir simulators were first built as diagnostic tools for understanding reservoirs that surprised engineers or misbehaved after years of production. The earliest simulators were physical models, such as sandboxes with clear glass sides for viewing fluid flow, and analog devices that modeled fluid flow with electrical current flow. These models, first documented in the 1930s, were constructed by researchers hoping to understand water coning and breakthrough in homogeneous reservoirs that were undergoing water flood.

1.1 INTRODUCTION

The Al Huwaisah Field is located in the northwest part of Oman, some 350 km WSW of Muscat and about 20km south of Yibal. The main structure was discovered in 1969 by AH-1. First oil started in 1970. **Error! Reference source not found.** gives the dates of discovery and first oil for the Al Huwaisah field and its flanks, Eastern Satellite and South West Area.

| Discovery and First Oil | |
|-------------------------|---|
| • | Main structure discovered in 1969 by AH-1 |
| • | Southwest area discovered in 1970 by AH-3 |
| • | Eastern Satellite area discovered in 1970 by AH-6 |
| • | First Oil in 1970 (Main Area & Eastern Satellite) |
| • | First Oil Southwest 1980 (AH-50) |

Table 1.1-1: Al Huwaisah Field Discovery and First Oil

The Reservoir at Shuaiba level is a large, low relief faulted dip closure with local Faults. It is approximately 26km long by 12km wide. Top structure is located at a depth of 1435 m. Maximum relief above the revised free water level (1480 mTVDss) is 45 meters in the main area of the field.

Porosities range from 14% – 35%.

Matrix permeability is highly variable ranging from <1 mD to >1 D.

Reservoir is highly undersaturated

Bubble Point Pressure $P_b = 5,860$ kPa

Initial pressure $P_i = 17,160$ kPa

Oil has low viscosity (1.2 cp, 38° API).

Table 0-1: General description of Al Huwaisah field

| General | | |
|----------------------------|---|--|
| Location | 20 km south of Yibal field | |
| Size and shape | Flat gently dipping structure, 26 km long by 12 km wide | Maximum oil column thickness: 54m The field has been subdivided in a number of areas, based on structure and reservoir development: Main Area, Eastern Satellite, Southwest Area. |
| Depth | 1440 mTVDSS, 1520 m | |
| Main producing reservoirs | Lower & Upper Shuaiba | No oil/gas in overlying reservoirs |
| Geological Setting | Lower Cretaceous Rudist reef complex | Very heterogeneous reservoir properties; their effect on well inflow is poorly understood. Well reserves vary per facies type (50,000 to 3 mln m ³). |
| Initial pressure (Pi) | 17,160 kPa | Datum 1463 mss, based on Main Area |
| Reservoir Temp. | 81 °C | |
| Porosity | 10% - 25% | |
| Permeability | <1 mD to >1000 mD | Order of magnitude contrast between and within genetic units |
| Oil viscosity | 1.2 cp | |
| Oil density | 38° API | |
| Bubble point pressure (Pb) | 5860 kPa | Highly undersaturated oil (Pi = 17,160 kPa) |

The Al Huwaisah field has historically been subdivided in 4 areas which are the Main Area (MA), South West area (SW), Eastern Flank, Eastern Satellite (ES) and North Western Area. As per 2006 FDP, recovery from Main Area was estimated to be around 35% (Expectation case STOIIP) while from other areas (SW & ES) was significantly low at about 8% (Expectation case STOIIP). Thus the current study was established in order to investigate the reasons behind the low recoveries of SW and ES areas and to develop the two areas accordingly. Figure 1.1.1 shows area boundaries and ultimate recoveries.

Al Huwaisah - Shuaiba Fm. ULTIMATE RECOVERY FACTORS BY AREA
Expectation Case (FDP-2005)

| | STOIIP | Exptn. UR | RR 2008 | URF | CRF |
|--------------|--------------|-------------|------------|------------|------------|
| | MMm3 | MMm3 | MMm3 | % | % |
| MA+EF | 142.9 | 50.7 | 5.5 | 35% | 32% |
| ES | 31.6 | 2.5 | 1.0 | 8% | 5% |
| SW | 52.8 | 4.2 | 1.1 | 8% | 6% |
| NW | 18.7 | 0.0 | 0.0 | 0% | 0% |
| TOTAL | 246.0 | 57.4 | 7.6 | 23% | 20% |

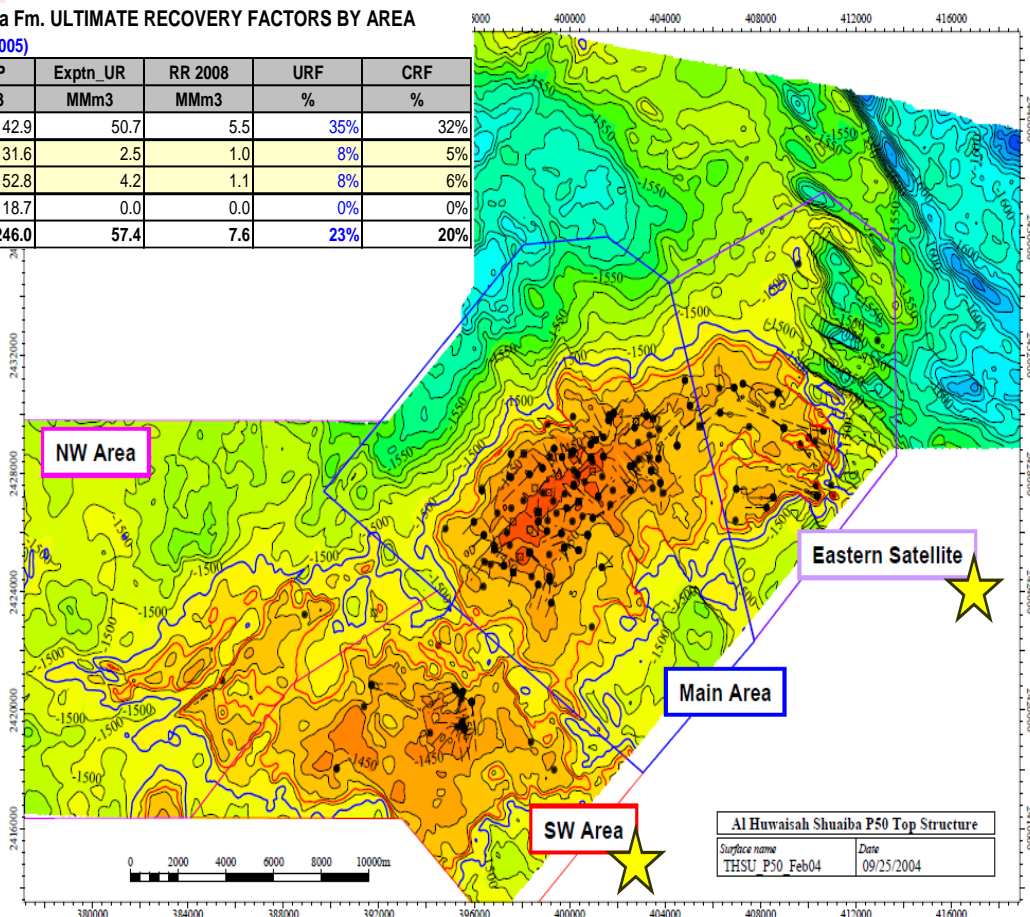


Figure 1.1.1: Main Area, its satellites and Ultimate Recovery

1.2 Summary of Field Development Plan-2005 and the Two Drilling Campaigns:

The last Al Huwaisah Field Development Plan was issued in early 2011. The study was conducted in the period 2007 – 2011. Models were built using information/data up to AH-132 and FDP was delivered early 2011. The FDP identified opportunities in Main area, South West and Eastern satellite for maturing hydrocarbon.

The final selected development was to drill:

- 19 horizontal oil producers in the Main area and
- 12 horizontal oil producers, 3 horizontal sidetracks and 5 vertical Water Injection wells in South West area.

The locations of proposed oil producers are shown in the **Error! Reference source not found.**

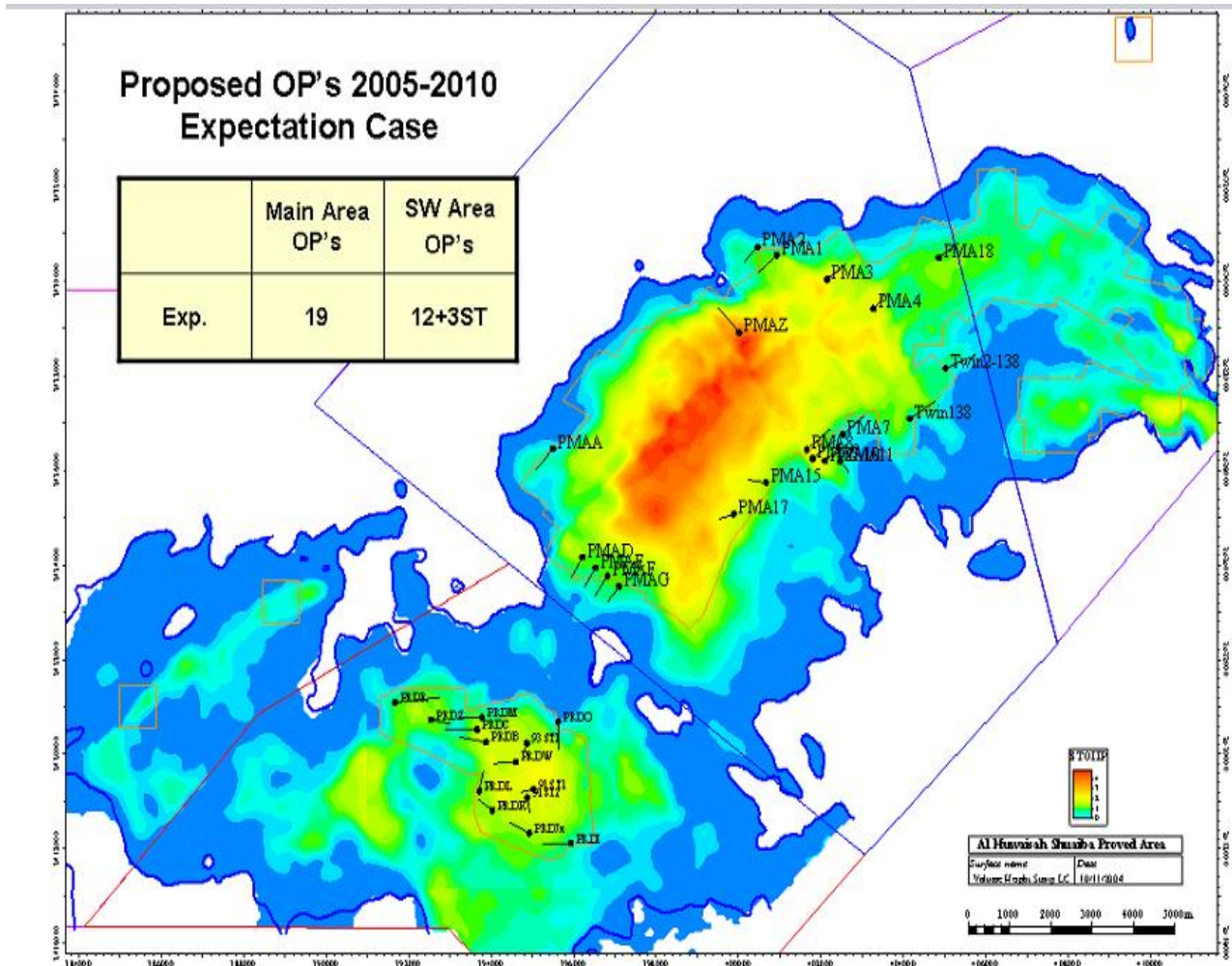


Figure 1.1.2: Al Huwaisah Shuaiba Development: FDP-2011

A phased infill drilling campaign was executed in 2010-2011 (Phase-I) and 2012-2013 (Phase-II) to mature the identified opportunities. Results of these drilling campaigns are summarised below.

1.3 Summary of 2010-2011 Drilling Campaign (Phase-I):

The wells drilled during this phase of drilling campaign have performed close to the expectation (with some variance and few exceptions). The comparison of drilling results as compared to the expectation (planned) numbers (initial oil rate and UR) is presented below in **Error! Reference source not found.** and Figure 1.1.3.

Table 0-1: Al HuwaisahShuaiba: 2010-2011 Drilling Campaign Results

| Area | Well | First Oil | Initial Oil Rate (m ³ /day) | | 30-Sep-15 | | Ultimate Recovery (UR) (MMm ³) | | Np (Cumulative Production) | Np/UR | Np/UR |
|----------|----------|-----------|--|--------|------------------------------|---------|--|--------|----------------------------|--------|----------|
| | | | Plan | Actual | Oil Rate m ³ /day | BSW (%) | Plan | Actual | (MMm ³) | Plan % | Actual % |
| SW | AH-147H2 | Feb-11 | 140 | 101 | 21 | 96 | 0.11 | 0.09 | 0.06 | 56% | 68% |
| SW | AH-149H2 | Mar-11 | 350 | 177 | 34 | 95 | 0.11 | 0.18 | 0.11 | 96% | 57% |
| Total SW | | | 490 | 278 | 55 | | 0.22 | 0.27 | 0.17 | 76% | 61% |
| MA | AH-152H3 | Jul-11 | 100 | 146 | 6 | 89 | 0.07 | 0.04 | 0.03 | 44% | 86% |
| MA | AH-153H2 | Apr-11 | 100 | 332 | 48 | 71 | 0.07 | 0.25 | 1.03 | 188% | 53% |
| MA | AH-154H3 | May-11 | 200 | 199 | 16 | 89 | 0.08 | 0.08 | 2.03 | 65% | 65% |
| MA | AH-155H1 | Jun-11 | 350 | 514 | 67 | 81 | 0.1 | 0.39 | 3.03 | 258% | 65% |
| MA | AH-156H3 | Jul-11 | 220 | 156 | 3 | 96 | 0.08 | 0.04 | 4.03 | 42% | 80% |
| MA | AH-157H1 | Jul-11 | 180 | 145 | 26 | 89 | 0.1 | 0.11 | 5.03 | 63% | 59% |
| MA | AH-158H2 | Aug-11 | 80 | 246 | 53 | 91 | 0.1 | 0.29 | 6.03 | 136% | 47% |
| MA | AH-159H4 | Sep-11 | 160 | 116 | 28 | 92 | 0.09 | 0.09 | 7.03 | 49% | 52% |
| MA | AH-160H6 | Oct-11 | --- | 101 | 12 | 98 | 0.1 | 0.05 | 8.03 | 38% | 84% |
| MA | AH-161H2 | Oct-11 | --- | 346 | 91 | 85 | 0.1 | 0.44 | 9.03 | 201% | 46% |
| Total MA | | | 1390 | 2301 | 350 | | 0.89 | 1.77 | 10.03 | 111% | 56% |

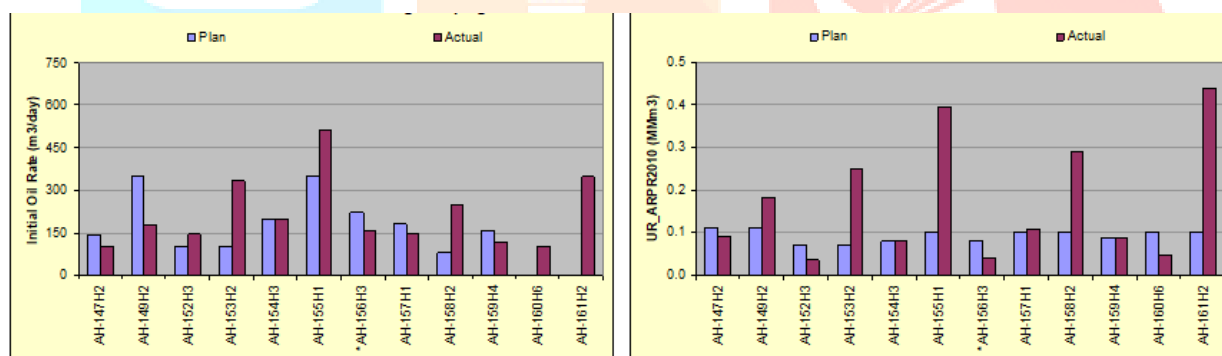


Figure 1.1.3: Al HuwaisahShuaiba: 2010-2011 Drilling Campaign Results

1.4 Summary of 2006-2007 Drilling Campaign (Phase-II):

The wells drilled during this phase of drilling campaign initially showed performance similar to the phase-I but subsequently, the performance of the drilled wells continued to decline as the campaign progressed. Performance of 4 wells (2 wells each in MA and SW areas) deviated significantly from the expectation figures and hardly produced any oil. This posed significant challenge to the FDP-2011 and further drilling was discontinued due to the lack of confidence in the remaining proposed locations. It was decided to understand the deviations and the reasons thereof prior to drilling any further locations in both the Main and South West areas.

The comparison of drilling results as compared to the expectation (planned) numbers (initial oil rate and UR) is presented below in Table 0-2 and Figure 1.1.4

Al HuwaisahShuaiba :2012-2013 drilling Campaign:

Table 0-2: Al HuwaisahShuaiba: 2012-2013 Drilling Campaign Results

| Area | Well | First Oil | Initial Oil Rate | | 30-Sep-2009 | | UR (MMm3) | | 30-Sep-2009 | Np/UR | Np/UR | |
|-----------------|----------|--|------------------|-------------|-------------|-----|----------------|-------------|----------------|-------------|------------|--|
| | | | (m3/day) | | Oil rate | BSW | Plan vs ARPR10 | | Np (Cum Prodn) | (plan) | (Actual) | |
| | | | Plan | Actual | (m3/day) | (%) | Plan | Actual | (MMm3) | (%) | (%) | |
| SW | AH-162H1 | Mar-06 | 149 | 60 | 22 | 95 | 0.07 | 0.08 | 0.03 | 44% | 37% | |
| SW | AH-163H1 | Mar-06 | 540 | 71 | 17 | 96 | 0.14 | 0.08 | 0.03 | 25% | 46% | |
| SW | AH-164H3 | | 55 | | | | 0.07 | | | | | |
| SW | AH-165H1 | May-06 | 262 | 126 | 24 | 96 | 0.14 | 0.10 | 0.06 | 41% | 56% | |
| SW | AH-168H2 | | 130 | | | | 0.09 | | | | | |
| Total_SW | | | 1136 | 257 | 63 | | 0.51 | 0.26 | 0.12 | 24% | 47% | |
| MA | AH-166H4 | Jun-06 | 540 | 171 | 80 | 87 | 0.05 | 0.29 | 0.14 | 284% | 49% | |
| MA | AH-167H1 | Jul-06 | 167 | 538 | 34 | 94 | 0.05 | 0.16 | 0.11 | 221% | 70% | |
| MA | AH-169H4 | Aug-06 | 260 | 603 | 48 | 87 | 0.09 | 0.29 | 0.20 | 224% | 68% | |
| MA | AH-170H3 | Sep-06 | 104 | 2 | 0 | 0 | 0.05 | 0.00 | 0.00 | 1% | 100% | |
| MA | AH-171H4 | Nov-06 | 92 | 87 | 29 | 87 | 0.04 | 0.05 | 0.03 | 80% | 67% | |
| MA | AH-172H3 | Water Injector in Main Area to maintain NFA production | | | | | | | | | | |
| MA | AH-174H2 | Apr-07 | 195 | 13 | 0 | 100 | 0.06 | 0.00 | 0.00 | 0% | 100% | |
| MA | AH-175H1 | | 158 | | | | 0.07 | | | | | |
| Total_MA | | | 1516 | 1414 | 191 | | 0.41 | 0.79 | 0.49 | 119% | 62% | |

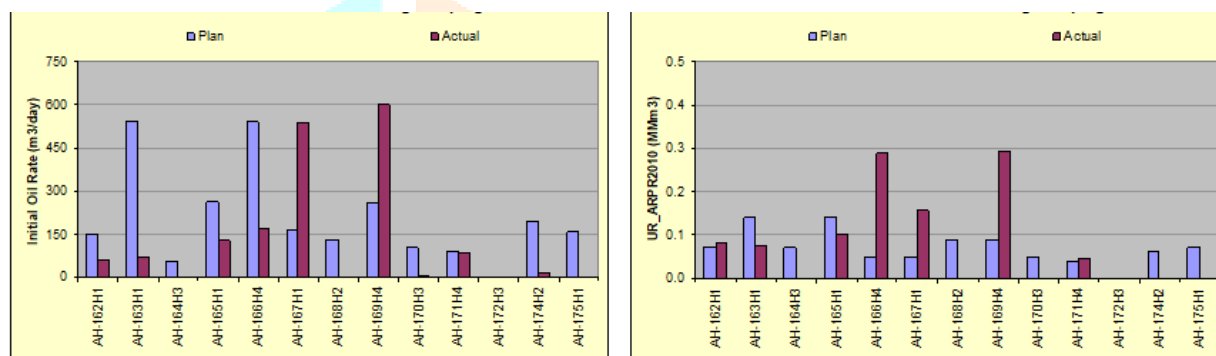


Figure 1.1.4: Al HuwaisahShuaiba: 2012-2013 Drilling Campaign Results

1.4.1 Summary of Main Area Development:

- 17 development producers were drilled out of 19 planned.
- 4 of the drilled producers were different than the ones identified in FDP.
- 14 wells performed more or less reasonable as compared to the planned initial oil rate and UR – some performed a bit higher and others a bit lower than expected.
- 3 wells did not perform (no or negligible UR).
- No WI was planned but 1 WI was drilled to:
 - maintain the inflow performance and safeguard reserves of BR wells
 - Re-inject some of excess AH(Al Huwaisah) produced water
 - Stop over-injection in Yibal.
- 2 producers were dropped

1.4.2 Summary of South West Area Development:

- 7 producers drilled out of 12 planned
- 5 wells performed more or less reasonable as compared to the planned initial oil rate and UR – some performed a bit higher and others a bit lower than expected.
- 2 wells did not perform (no UR).
- Remaining 5 producers were postponed.
- 3 Sidetracks dropped.
- 3 WI were drilled. 2 WI were dropped.

1.5 Conclusion:

The highest gain in incremental recovery is from the “*Horizontal Infills + Peripheral WF*”. This development option gives about 36% recovery (unrisked) in SW area.

- (a) **Phase-I:** Quick and early winner through phased drilling of few wells (producers + injectors) that can be supported by existing facilities by small additions / alterations by 2019. #Producers: 4 in SW.

#Injectors: 4 in SW.

- (b) **Phase-II:** Phased drilling of remaining wells (in the feasible option) starting around 2023 once surface facility upgrade for additional wells become available.

#Producers: 11 in SW.

#Injectors: 5 in SW.

1.6 References

- [1] Al Huwaisah Shuaiba, Field Development Plan, Al Huwaisah Project Team, ONP/REP/021/2005/F, Huw Davies, ONPY/4H, 2005.
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- [6] Al Huwaisah Shuaiba Conventional Study (South West Area + Eastern Satellite): Petrophysical Discipline Report