

## **Abu Dhabi, UAE Experiences in Gas Injection**

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### **1. Introduction**

In the UAE, utility of gas injection for displacement efficiency is closely monitored in order to assess benefits of utilizing gas for enhanced oil recovery "EOR". Several gas injection pilots to study mechanisms for optimization of development plans in Abu Dhabi onshore and offshore field are currently underway. Salient features of gas injection projects will be discussed especially in the context of inherent heterogeneities that are encountered in the carbonate reservoirs of the region. Due to its uniqueness, an example from the Emirate of Dubai will be discussed.

Crestal gas injection in oil reservoirs with gas caps is a common pressure maintenance scheme in Abu Dhabi reservoirs which are often accompanied by one or more water injection schemes including peripheral, pattern or line drive. Examples will also include gas injection for condensate recovery by recycling produced gas from gas condensate reservoirs, in addition to an acid gas injection project in offshore Abu Dhabi.

### **2. Cases Studies:**

#### **Field A**

##### **Enhanced Oil Recovery**

A giant onshore field with several producing horizons belonging to the Early Cretaceous Thamama group has the prolific Reservoir-X, which is defined by permeability contrast between the Lower subzone X-Lower and the X-Upper subzone with ratio of 1:10 in the south of the reservoir and 1:5 in the north with a generalize trend of properties deterioration northwards. This contrast, superimposed with resident major faults, vertical seismic and sub-seismic faults and fractures define the challenges of managing and optimizing recoveries from this and similar reservoirs of this formation in the UAE. Gas injection schemes in the reservoir include crestal gas injection, pattern gas injection in the north of the reservoir and a dual water-gas injection pilot in the south .

##### **Crestal Gas Injection**

Five crestal gas injectors inject more than 200 MMSCFD, of which two of are horizontal injectors in the north and contribute to about 100 MMSCFD providing excellent pressure support to the pattern gas injection scheme in the north of the injectors (it is suspected that a fault south of the two injectors probably acts as a baffle to lateral distribution of the pressure to the south). Plans are in place to redistribute gas injection and add additional injectors to provide pressure support to the south and to prevent condensate dropout and oil migration to the gas cap a pressure declines

##### **Pattern Gas Injection**

In the same reservoir, inverted 5-spot pattern schemes comprising nine horizontal gas injectors was begun in 1996. All gas injectors were completed in X-lower, while six producers were completed in X-Upper and thirteen in X-Lower. One of the patterns is designated as a pilot with observers.

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Initial injection of over 90 MMSCFD of lean gas, begun in 1996, was reduced to 54 MMSCFD in 2003 due to overly high pressures above initial pressure.

As predicted by simulation ten years ago, currently 10 out of the 19 producers have gas breakthroughs. From the simulation prediction runs, the oil production is estimated to decline by 2013 and a re-development strategy is being sought to maintain current and additional production.

The observers in the pilot pattern indicate that gas is moving preferentially to X-upper due to gas gravity over-ride, vertical permeability contrast and possibly presence of subseismic faults and fractures. The volumetric sweep in the X-Lower is not optimized as oil is by-passed. Compositional simulation has identified optimum recovery with a development scenario of line-drive with WAG-CO<sub>2</sub> (and additional infill wells). Injecting denser supercritical CO<sub>2</sub> at reservoir conditions would reduce gas over ride and increase both volumetric and microscopic displacement.

Availability of CO<sub>2</sub> gas is currently envisaged to come from capture of flue gas from utilities which would serve also the purpose of reducing Carbon Dioxide emission to the environment.

A water injectivity pilot is proposed as a prelude to WAG-CO<sub>2</sub>. Laboratory studies are currently ongoing and include PVT analysis for CO<sub>2</sub> MMP of original and variously stripped oil compositions, asphaltene flocculation study, coreflood studies for gas processes which will include pure CO<sub>2</sub> and acid gas in secondary and tertiary recoveries.

A dual water and gas injection pilot which is located in the south of the field, had water injector in the higher permeability X-Upper and a close by gas injector injecting in X-Lower. Gas preferentially moved to X-Upper but due to the pressure boundary created by water injection, gas was seen to break in the opposite direction of the water injector.

### **Condensate Recovery by Gas Recycling**

A deeper condensate reservoir of Field A producing condensates by recycling (re-injecting the produced lean gas) is predicted to produce additional 0.5 BSTB of condensates with the recycling mode as compared to non recycling of produced gas. The process also maintains reservoir pressure.

## **Field B**

### **Tertiary Miscible**

The concept of confining pressure to control pressure boundary is also exploited with great success in Field B-a mature water flooded field in offshore Dubai<sup>1</sup> for a Middle Cretaceous Carbonate reservoir of the Mishrif formation. The tertiary miscible WAG pilot was composed of a horizontal WAG injector straddled by two horizontal producers. The three-well pattern was surrounded by four water injectors providing confinement and pressure control. After four years of operation, incremental oil rate was obtained with a peak of 400%. A previous scheme without confinement caused gas dispersion and did not achieve the expected results. Compositional simulation runs indicate that incremental recovery over waterflood is around 6% of OOIP for 0.15 HCPV of injected gas in the pilot area.

## **Field-C**

### **Tertiary Non-Miscible**

Tertiary recovery from an Upper Jurassic waterflooded mature Field-C offshore Abu Dhabi<sup>2</sup> is the first full field tertiary recovery project in operation in the UAE. The project was begun in 1997 after extensive laboratory investigation (PVT, long core tertiary recovery SCAL experiments) where the results indicated that swelling, rather than miscibility would enhance recovery. Two pilots in 1991 and 1993 were carried out as prelude to the full field operation. Full field implementation targets pockets of oil bypassed by heterogeneity and tighter formation. Significant incremental oil has been recovered.

## **Field D**

### **Acid-Gas injection**

A small field in offshore Abu Dhabi<sup>3</sup> is the sole current example of enhanced oil recovery using re-injected gas with high H<sub>2</sub>S and CO<sub>2</sub> content as miscible gas displacement. All operational constraints were overcome and the field is successfully operational.

## Other Pilots

Pilots to investigate various probable recovery mechanisms are underway in several fields. The presence of heterogeneity associated with the presence of high permeability streaks causing early breakthroughs of injected gas remains the main challenge. However, some positive responses have been observed:

- In one example, in a waterflooded zone, a pilot producer under gas lift with very high water cut responded initially with increased water cut followed by incremental oil rates and resultant decline in water production i.e. (water cut reduced from 80% to 40 % and oil rates doubled). Subsequently, incremental GOR naturally gas lifted the oil.
- In another case<sup>4</sup>, a combined miscible secondary in Lower subzone and tertiary in the waterflooded upper subzone indicated that incremental oil recovery from the tertiary process was being achieved.

## Conclusions

Currently, gas injection schemes have successfully showed preliminary encouraging results in many of the pilot projects. Gas injection for both secondary and tertiary recovery is considered as one of the most promising method to boost ultimate recovery in Abu Dhabi fields.

Several gas injection schemes for secondary recovery in tighter reservoirs of Abu Dhabi are either already implemented or planned to be implemented.

Continued close monitoring will provide further understanding of enhancement mechanisms of gas injection. Sector simulation models will provide an outlook for long term benefits.

Simulation studies have indicated that with water injection schemes, the recovery factors are limited to between 30-35 %, whereas combined water and gas injection schemes, where applicable, would extend the oil recovery to over 60%.

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