A FRACTURED CARBONATE FORMATION in the Egyptian eastern desert was saturated with heavy oil, the hydrocarbons having migrated up from much deeper source rock. In doing so, the oil lost most of its light hydrocarbon elements as well as its pressure drive. As a result, wells in the 30-year-old Issaran Field were being produced using sucker rod pumps augmented by steam injection to reduce viscosity.

Water had broken through, with ingress suspected at several levels, and water cuts up to 98 per cent experienced in several field wells.

Much of the water came either from high water saturation intervals with low saline water (5000-10000 PPM) or from condensed steam and was fresh, with resistivities up to 30 ohm.m, making it difficult to discriminate from hydrocarbons using traditional resistivity measurements.

Although the field was estimated to hold up to 700 MMBO of 10-12 degree API crude, primary recovery factors were as low as one per cent, with ultimate recovery of less than 30 per cent.

The Issaran Field is located about 180 miles (290-km) southeast of Cairo along the western shore of the Gulf of Suez (Fig. 1).

Four principle shallow (1000-2000 ft) production zones have been identified. The Upper and Lower Dolomite formations are classified as fractured dolomite formations with average reservoir thicknesses of about 400-ft (122 m). Formation pressure and temperature are as low as 250 psi and 120°F (49°C) respectively. The reservoir is oil-wet, which has a negative effect on recovery factors.

The third formation, the Gharandal, consists of three relatively tight limestone bodies, and the lowest formation is the highly-fractured Nukhul limestone. It could be assumed that a network of highly-conductive natural factures might benefit production, the opposite was the case.

The fractures were suspected of channeling the steam away from the near-wellbore regions, thus reducing its thermal effectiveness.

In addition, the Nukhul formation was characterized as having several extremely high-permeability layers, called Super-K layers, that were suspected of flooding the wellbore with large amounts of water.

Average production from Issaran Field wells was less than 30-50 bo/d per well, with 10-20 per cent H2S.

Steam injection to augment production was commenced in 2006 using the huff-n-puff technique. The operator, Scimitar Production Company, had tried a variety of completion and production techniques from open hole and cased hole cold production in the Gharandal and Nukhul to the aforementioned steam flooding in both the Upper and Lower Dolomite formations.

The operator decided on an innovative production scheme combined with a thorough dynamic evaluation program.
The objectives were clear: identify the water sources, evaluate the contribution from the different zones and determine if there was inter-zonal cross flow.

It was quickly determined that to accomplish these objectives the completions had to allow simultaneous logging and pumping. Moreover, the pumps had to deliver very high drawdowns at various rates to achieve the dynamic flow conditions required.

To allow simultaneous logging and pumping, the ESPs were equipped with a Y-tool bypass system that comprised of a concentric through-tube so the logging tool string could pass the pump and enter the completion zone(s) beneath it (Fig. 2). The pump was centered and held in a ‘saddle’ so pumped fluid could pass through the Y-tool and into the main wellbore tubing. Previous experiences with Y-tools were topped at 1,000 b/d because the centralised configuration limited the size of the ESPs that could be used. However, to achieve the desired dynamic conditions for production characterization and evaluation, the operator needed a pump that could produce at least 4,000 b/d.

Schlumberger provided a 400-series ESP that could deliver the required flow rate and drawdown. It was controlled by a variable speed drive so different flow rates could be created. This allowed development of the dynamic conditions needed to evaluate the wells.

**Slim sensors specified**

Now that the required dynamic flow conditions were deemed to be achievable, attention turned to measurement of the production parameters required to meet the evaluation objectives.

Schlumberger engineers recommended the PS Platform* production services platform.

This is a versatile combinable tool system that can be configured with a variety of sensors. The particular configuration chosen featured a Flow-Caliper Imaging Tool consisting of an X-Y caliper fitted with the FloView’ holdup measurement tool on each caliper arm, a directional fullbore spinner flowmeter and a relative bearing sensor.

Further up the tool string was an in-line spinner flowmeter, a Gradiomanometer* specific gravity profile fluid density tool, and a pressure/temperature cartridge featuring CQG* crystal quartz gauges. Accurate depth control was provided by a gamma ray detector and casing collar locator.

A telemetry cartridge ensured real-time data transmission to the surface from all sensors. Together, with necessary weights to allow well entry under flowing pressure, the entire tool string measured 34.5-ft (10.5 m) long.

Since the drift inside diameter (ID) of the Y-tool was 1.698-in, (43.1 mm), the entire PS Platform tool string diameter was limited to 1 11/16-in. (42.86 mm) leaving a mere 0.1 mm clearance.

Before running the tool into any wells, the clearance was verified in the shop by passing it completely through a Y-tool without difficulty. Also, to facilitate re-entry into the tubing string, a tapered re-entry guide was fitted to the tail pipe.

The FloView holdup meter measures dynamic water cut using a series of electrodes mounted on each caliper arm. Electric potential is created between a probe electrode and the ground.

If continuous phase hydrocarbons are flowing past the probe, they act as an insulator and no current flows to the ground. However, if any conductive water bridges the gap between the probe and the groundwire, current flows, and water is detected.

Holdup is calculated by measuring the relative time water is detected compared to hydrocarbons. Crossflow is measured by comparing spinner velocities. If both are spinning at the same rate and direction, there is no crossflow.

The first well evaluation involved an openhole cold oil producer completed in the Nukhul formation. The well was producing 6,000 b/d with 98 per cent water cut, but then water cut increased, dropping oil production to 20 b/d.

Three surveys were run, two dynamic surveys at 70 Hz and 80 Hz respectively, plus a shut-in survey. In the 140-ft (42.7 m) openhole interval, four producing zones were identified. Only about 30-ft (9 m) of the open hole was contributing oil.

The remainder of the intervals contributed most of the water. During the shut-in survey, a clear indication of cross flow was observed into the top most zone.

The decision was made to set and cement a 5-in. liner across the entire openhole interval to cut off the water; then perforate and recomplete only the oil interval. This boosted oil production to about 70 b/d (Fig. 3).

The second well evaluated tapped the Lower Dolomite reservoir in an openhole completion but it had failed to produce any oil. Logs confirmed that all intervals of resistivity less than 30 ohm.m produced water.

While oil remained unproductive, the evaluation allowed interpreters to re-define a 30-ohm.m cutoff for water production and apply it field-wide, saving interpreters from counting on hydrocarbon production from zones actually containing freshwater.

The third well tested penetrated the Nukhul reservoir, and had been completed as an openhole cold producer. Shortly after completion, the well started producing 6,000 b/d with 100 per cent water. It was further observed that shutting-in this well caused an increase in water cut in offset wells.
Two dynamic surveys were taken at 70 Hz and 75 Hz respectively plus a shut-in survey. During this latter survey, a clear downward cross flow was observed from the upper producing zone. This explained the increase in water cut observed in the offset wells during shut-in periods. The entire openhole interval produced no oil, so the well was plugged-back and recompleted in the Gharandal formation.

During plug-back operations, the openhole interval was thoroughly cemented up to eliminate the cross flow and reduce the water cut in the offset producers.

**Valuable answers to reservoir puzzles**

The information derived from the three wells surveyed provided excellent insight to the cause and the source of both water ingress and cross flow. The Y-tool completion, with its high-rate ESP, allowed excellent dynamic and drawdown conditions to be established so downhole conditions could be thoroughly diagnosed.

Accurate pressure analysis for each interval confirmed variable pressure conditions throughout the reservoir, even in the same formation.

Perhaps most valuable were the insights affecting future field development plans. With the 30 ohm.m cutoff established, high resistivity indications would not be misinterpreted as hydrocarbons without further evaluation.

Wells exhibiting this condition were recompleted with water-bearing zones isolated. This practice alone resulted in a reduction of water cut from over 90 per cent to less than 50 per cent.

**New development plans**

Several changes were made with each formation affecting the Upper and Lower Dolomite completions as well as the Nukhul completions. In the latter, the key to increasing oil production was increasing drawdown. Using the new, powerful ESPs allowed well production to be stepped up to 20,000 bbl/d, thus boosting oil production while simultaneously reducing water cut in surrounding wells.

In the Dolomite formations, a two-pronged plan was implemented. A pilot study on some new wells involved completing them as cased hole producers. The objective was to calculate the trade off between shutting off the water production with cemented pipe versus the effect of pressure drop through the perforations.

Results of the pilot test confirmed good oil production from the cased hole completions compared to little oil production from the openhole completions.

The second part of the plan applied to existing Dolomite wells. The injector well strategy would be redesigned to relocate injector wells throughout the field, and complete them using 5-in. liners with selective perforation in high oil saturated zones.

Steam would be injected into these zones being careful to avoid highly-fractured zones that would conduct steam away from the near well-bore areas. This technique would maximize pressure support and heat transfer to reduce viscosity.

Continuous steam injection into carefully-selected wells was substituted from the huff-n-puff technique, and resulted in a boost in oil production of 40 bo/d in surrounding producers.

The combination of high-volume ESPs with accurate flow analysis using a multi-sensor production logging tool in both static and dynamic flow conditions, effectively solved the evaluation challenges and led to a practical solution to field production challenges.

* Mark of Schlumberger