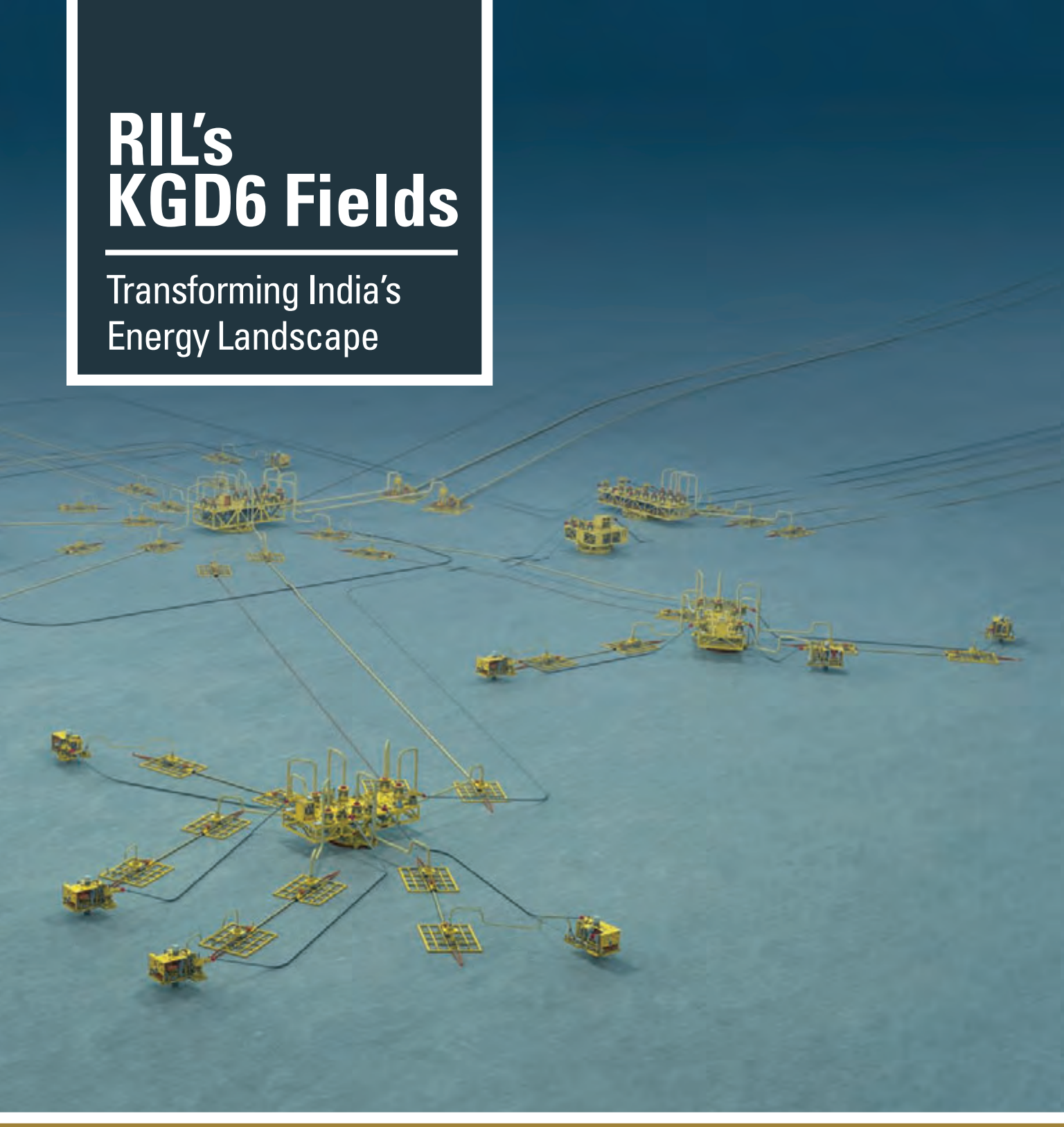
RIL's KGD6 Fields

Transforming India's Energy Landscape



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Reliance Industries Limited

Integrated Project Teams Achieve Fast-Track Conclusion at KG-D6

Aggressive development schedule challenge met by Reliance, Schlumberger

From the very start, Schlumberger has been involved in developing deepwater projects, contributing its marine seismic, data and consulting, reservoir evaluation and wireline, drilling and measurement, testing and other uniquely related technologies and services for the exploration, completion and production phases. Based upon RIL's unique needs for the KG-D6 development, Schlumberger has applied several new game-changing completion and production monitoring technologies.

The *Geco Eagle* acquired over 400 miles^2 of seismic data over the KG-D6 block.

Seismic to exploration well target selection calls for new geobody model

In 2001, RIL awarded the first 3D seismic survey on the KG-D6 block to Schlumberger's WesternGeco business unit, whose state-of-the-art vessel *Geco Eagle* acquired some 463 miles^2 of seismic data, which revealed several areas of interest for possible subsequent drilling. The processing of this initial survey identified a reservoir of interest among what was described as a very laminated and sinuous body of channel-fan complexes stacked together to a gross thickness of some 1,150 ft.

Reliance needed a new approach to capture the exact vertical extent of the channel-levee complex to delineate the reservoir and estimate volumetrics more accurately.

Reservoir modeling experts with Schlumberger Information Solutions (SIS) joined in a multidisciplinary team effort with RIL geologists, geophysicists and reservoir engineers in designing a new, more reliable geobody interpretation workflow program using SIS' Petrel* seismic-to-simulation software for representing reservoir features.

The advanced Petrel technology provided the team with a single, integrated platform from which to execute a complete workflow. Additionally, the software's ability to incorporate data from various other analyses allowed the SIS-RIL team to include a detailed thin-bed characterization and petrophysical analysis from core data in a new reservoir model.

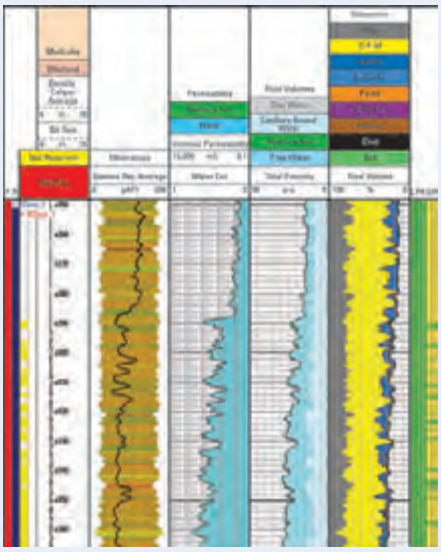
Using Petrel's geobody extraction tool allowed the team to complete the complex job in only about one-fifth of the time typically required by conventional aerial demarcation technology. Using Petrel markedly increased the effectiveness of the team's ability to model the reservoir and compute volumetric estimates.

Safe, efficient well LWD

From the beginning, RIL's main objectives at the Dhirubhai project were safe drilling and accurate formation evaluation. Operating in a region widely known for its extremely hostile weather conditions, including frequent tropical cyclones (typhoons) with winds of more than 100 mph, waves of up to 65 ft. (20 m) and subsea currents of more than 4 knots, the KG-D6 drilling posed challenges for even the three all ocean-rated, dynamically positioned drillships used for drilling and completions. What's more, once drilling began, Reliance faced challenges in acquiring log data in an area where wells had never before been drilled.

Anticipating a long line of similar challenges, the company took special care in choosing its project stakeholders. For the drilling and measurements (D&M) and wireline (REW) work, RIL again chose Schlumberger.

Once drilling began, Schlumberger and RIL collaborated in using drilling performance measurements made with LWD tools to enhance drilling performance and safety. Combining LWD data both in the field and in off-site planning centers allowed the drilling team to highlight formation attributes. It also helped them to identify crucial problem areas for which drilling engineers were able to take real-time corrective drilling measures, if necessary. Using real-time caliper data, for example, revealed hole shape and condition, thus making it easier to evaluate formations and to make appropriate completion decisions.



The EcoView* answer product assists in the analysis of the comprehensive data suite from the EcoScope service.

Schlumberger provided a full suite of LWD logs, including real-time caliper and the company's adnVISION* azimuthal density neutron service for real-time neutron porosity, formation bulk density and photoelectric factor data to characterize formation porosity and lithology while drilling, identifying and quantifying potential pay zones.

Particularly useful during LWD operations was the use of the EcoScope* multifunctional LWD service, which integrates a full suite of data formation evaluation in one compact single 26 ft. collar. Use of this service reduced the risk often associated with the multiple collars necessary for conventional triple combo logs in vertical well sections. In addition to resistivity, neutron porosity and azimuthal gamma ray and density, EcoScope provided while-drilling measurements of elemental capture spectroscopy and sigma.

InterAct carries well data globally

Additionally, the drilling team employed Schlumberger's InterACT* real-time monitoring and data delivery system to transmit well data from drilling locations to reservoir engineers' desktops at RIL's headquarters in Mumbai, as well as to those in the Schlumberger network of Operation Support Centers. These centers have experts who monitor drilling operations in real time, 24/7. Using a standard Web browser and intranet connections, InterACT helped to enhance the collaborative abilities of both well site and off-well site specialists in India and elsewhere around the world to leverage their decision making, enabling RIL to focus multiple, disparate and specialized resources on both individual wells and, subsequently, well clusters.

As identified by the LWD service, the formation of interest in KG-D6 is comprised of massive sands interspersed with a significant number of thin beds. So, the drilling team combined resistivity data from LWD with those recorded by Schlumberger's wireline-conveyed HRLA* high-resolution lateralog array tool in combination with the rugged PLATFORM EXPRESS* logging system.

New logging technology identifies additional reserves

In vertical wells with thick, homogeneous horizontal beds, standard resistivity logging tools like the AIT array induction imager tool deliver satisfactory data. In some KG-D6 wells, however, gas contained in laminated sand-shale sequences might have been overlooked due to the effects of anisotropy, where the thin beds all exhibit higher and/or lower resistivities, i.e. where conductivity in one direction – say, parallel to one layer – differs from that in another direction – say perpendicular to an adjacent layer. What's more, in such thin sand-shale turbidite sequences, many layers are thinner – in the millimeter range – than the vertical resolution of conventional wireline-conveyed induction logging tools, which have a minimum 1-ft (0.3-m) resolution, and even less than the 1.2-in. (3-cm) vertical resolution of typical porosity tools.

Certain HG-D6 wells were deviated to the extent that gravity decent wireline logging would not work. Pipe conveyed logging was chosen rather than LWD.

One such critical tool to deliver understanding of the laminated sections was the OBMI* oil-base microimager tool. This expanded the drilling team's understanding of the distribution of the thin beds and a more accurate sand count. In addition the vertical seismic imaging tool (VSI) enhanced the structural model and revealed rock property information that could be used for geomechanical study, enabling RIL to plan for the future production phase.

Engineer performs operational checks on the OBMI tool before a job.

Also included in the open-hole wireline logging tool combinations employed were the Rt Scanner* triaxial induction service, the Sonic Scanner*acoustic scanning platform and the PressureXpress* (XPT) reservoir pressure while logging tool selected because they were judged to deliver the required data in the most efficient manner.

For a deeper understanding of the true resistivity of the laminated pay sections, the Rt Scanner triaxial induction service, which measures formation resistivity both perpendicular and parallel to the direction of the laminated silt-sand layers (Rv and Rh, respectively) was utilized. (Note: The tool also provides

The real-time data transited via a Schlumberger teleport, before reaching the RIL reservoir engineer's desktop.

traditional AIT type measurements.) Taking measurements at multiple depths of investigation in three dimensions provided a true 3-D resistivity map. The enhanced hydrocarbon and water saturation estimates computed from these measurements resulted in a more accurate reservoir model and finer reserves estimates, particularly for the laminated, anisotropic formations.

Reservoir summation results derived by the Rt Scanner demonstrated that for the complete logged intervals, net pay thickness value was 1.35 times higher than that produced by the basic AIT tool. Additionally, the Rt Scanner-derived net pay hydrocarbon porosity thickness was 1.55 times larger than that of the corresponding AIT, which translated to a 700% additional net pay.

Single-pass sonic tool delivers quick formation evaluation

During drilling certain borehole sections exhibited radial plastic yielding caused by stress concentrations resulting in drilling-induced damages. Wireline formation pressure and sampling testing of such intervals resulted in lost seals or tight pre-tests. This increased the time to realize successful pressure and fluid samples at a cost proportional to expensive rig spread rates, far greater than the cost of the service itself.

To evaluate the formation alteration in subsequent, similar well intervals, RIL employed Schlumberger's Sonic Scanner tool to evaluate both far field and near field slowness. Unlike other sonic tools, which deliver mostly near wellbore data, the Sonic Scanner also is capable of measuring deep formation slowness at varying radial depths. The tool is equipped with 5 transmitters and 104 receivers, with a unique dipole source design that enables it to be fired in either pulse or "chirp" mode. Slowness identification using the Sonic Scanner aided the RIL-Schlumberger drilling team in denoting optimal pretest/sampling point selection, thereby saving considerably in nonproductive rig time. The tool also proved beneficial for evaluating radial acoustic behavior behind cemented casing intervals.

The Sonic Scanner tool provides the benefits of axial, azimuthal, and radial information for near-wellbore and far-field slowness information.

In comes the MDT

Once initial drilling was completed, RIL decided to conduct reservoir tests only in very promising zones and integrate other, lower-priority zones with an alternative method that would take less time and expense.

Working closely with Schlumberger Data and Consulting experts, RIL chose the MDT* modular formation dynamics tester, coupled with a dual packer, interval pressure transient testing tool – and integrating them into a single-well predictive model (SWPM) analysis to determine formation parameters and estimate well deliverability. InterACT real-time monitoring was used to transmit the test data to RIL engineers in Mumbai.

The interval pressure transient tests were conducted using the MDT's straddle packer system. The transient sequences consisted of single or multiple flow periods induced using a downhole pump, followed by periods of pressure buildup. The results were then used for the numerical single-well model to predict the commingled deliverability of several layers.

The success of single-well simulation and commingled approach allowed RIL to forecast absolute open flow potential (AOFP) for multiple zones. Well deliverability estimates were included using production tubular and choke information in the simulation model. According to RIL, this approach resulted in significant savings in rig time/cost by providing productivity estimates and AOFP without having to resort to conventional four-point deliverability tests.

In addition to the MDT sampling program, RIL also responded enthusiastically to the use in specific cases of Schlumberger's PressureXpress reservoir pressure measurement tool for both lower and higher mobility sands of up to > 500 md/cp.

MDT packers are inflated to isolate a reservoir zone for fluid sampling and pressure measurements.

More drilling, seismic further expands KG-D6 play

After drilling and testing the initial wells, RIL chose WesternGeco to conduct a detailed, 3D seismic survey over the most promising areas covering some 1,120 miles^2 in the KG-D6 acreage.

The high quality of the data lead to a detailed seismic attribute interpretation; and 12 of 13 exploration wells hit the target structure and found commercial hydrocarbons.

Meanwhile, WesternGeco returned to the block for the third time, in this instance to acquire 875 miles^2 of 3D data, to cover the complete block concession with 3D data. This was done mainly to identify the presence of geological features similar to those in which discoveries already had been drilled, and to determine whether it was justifiable to declare the entire block as a discovery area.

In view of the resulting significantly higher hydrocarbon potential, coupled with a growing deficit in India's projected natural gas supply for the immediate future, RIL in 2006 obtained government approval to double its daily KG-D6 gas production and to enhance facilities for production, collection and handling of gas both offshore and onshore. A revised estimate of capital expenditures for the enhanced production profile rose to about US$5.2 billion.

Part of the new spending for development of Dhirubhai 1 and 3 included the need for special/advanced pro-

cessing and interpretation of already acquired seismic data, as well obtaining still more 3D data. For the latter, RIL decided to acquire high-resolution Q-Marine* point-receiver 3D data – the first time WesternGeco's Q-Marine technology would be used off India.

RIL called for Q-Marine data acquisition with pre-processing onboard, followed by integrated onshore processing and inversion of the acquired seismic data to address some of the uncertainties in the reservoir description, reserves estimation, and well target selection and placement.

WesternGeco mobilized the *Geco Topaz* for the job in 2007 to meet not only the demanding geophysical challenges of the development survey but also because the Q-Marine technology she deployed enhanced the ability to maneuver in and around a crowded field of drillships, jackup rigs and host of support and survey vessels. The steerable streamer technology made a significant impact with minimum lost time and safe passes, and, perhaps most importantly, coverage of the entire survey area with no gaps in data coverage.

Impressed with the completion of the 170 mile^2 survey ahead of time and meeting their objective for the KG-D6 gas fields, RIL then decided to extend the development survey to the 123-mile^2 MA oil field, which was promptly completed in a similar fashion.

Live well operations performed safely from a dynamically positioned vessel

For field development, RIL elected to drill and complete 18 strategically placed subsea production wells in the two KG-D6 gas fields and in the adjacent MA oil field, each well equipped with dual open hole gravel pack completions. Early production data would be used to delineate the reservoir and define connectivity and compartmentalization. Petrel was used to demarcate the geobodies.

The wells were batch drilled, with one drillship doing the lower completion and a second following behind for the upper completion. However, a major issue was how to conduct the live well operations safely from a dynamically positioned vessel with the added risk of severe monsoon weather conditions. The subsea landing string system incorporating SenTREE* 7 subsea test tree and SenTURIAN* electrohydraulic operating system provided the solution for efficient and safe access to the dynamic reservoir parameters. Schlumberger has been providing subsea landing string services for over 35 years, and the evolution continued on this project with the first application of SenTURIAN.

Schlumberger introduced the SenTURIAN subsea landing string electrohydraulic operating system on this project to deliver reliable subsea well control, with an emphasis on improved offshore operating efficiency. It is the world's first and only in-riser system design and certified in accordance with the International Electrotechnical Commission's IEC 61508 SIL 2 reliability specifications for safety-related systems. It features an innovative, modular system that is much simpler to operate and smaller than comparable systems, allowing rig-time savings of as much as 50% during handling under certain circumstances. The modularity of the system's design also makes it ideal for job-specific customization. It is designed to operate from dynamically positioned vessels in all subsea applications, including deepwater and HPHT wells, in waters as deep as 15,000 ft.

SenTURIAN subsea landing string electrohydraulic operating system

SenTURIAN is the first landing string system to use interchangeable mandrels and pressure-balanced accumulators. This allows both subsea control and accumulator modules to be combined in a single assembly, which is 50% shorter than other systems, while providing the tensile strength, pressure rating, and hydraulic output needed for the full range of water depths. The operating system has programmable emergency shutdown levels that can be configured to close all subsea test tree valves to shut in a well and unlatch the landing string in less than 15 seconds.

Reservoir illumination without intervention

Because of reservoir uncertainties with respect to zonal contribution and inter-well connectivity, RIL called for an advanced measurement system to be permanently installed along the sandface of six of their wells. This system would supply real-time temperature and pressure data as well as an array temperature profile to be used for flow-profiling, tracking depletion, identifying water breakthrough, and making other critical production and reservoir evaluations. This system would provide an extra dimension to the pressure interference testing traditionally used to map out connectivity, which was to be used in the remaining 12 wells drilled.

To deliver on this requirement, Schlumberger deployed its new WellWatcher Flux* digital sensor array system in the six designated wells with the goal of establishing a complete real-time communication chain from the sandface to the RIL offices in Mumbai.

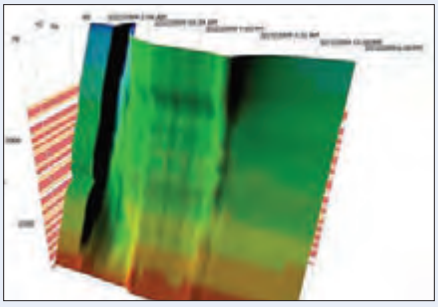
Integrated into the completion, the WellWatcher Flux system is designed to transmit data via a unique inductive coupler that links sensors on the gravel-pack to traditional permanent gauge hardware on the upper completion. The sensors are miniaturized, high-resolution, platinum resistance temperature devices located inside a small housing.

During manufacturing, according to RIL specifications, between 15 and 25 sensors were welded to a continuous control line to create a spoolable array for each well. The arrays were designed to be clamped along joints of each sandscreen as they were run in hole. Splicing and small depth adjustments could be made to each array during deployment if that proved necessary. The sensors measure the completion temperature which, in turn, is determined by the temperatures of both the incoming and wellbore fluids.

The inductive coupling, through wireless, allows transmission of power from the upper to the lower completion, as well as communication between the completion stages. Verification runs were made before running the upper completion to check integrity of the formation isolation valve, take a measurement of geothermal temperature and, most importantly, verify good communication across the inductive coupling. All six couplers worked flawlessly according to Reliance. Once the upper completion was landed, activation of the subsea tree penetrator brought the sandface data on line.

'Side Effects' deliver even more data

With the surface test equipment in place, the wells were cleaned up to avoid any excess completion fluid being passed into production facilities. The sandface data showed each zone cleaning up as gas displaced the completion fluid, generally progressing from the top of the well downward. But in many wells, the sandface data showed more than that. Several of the wells showed cross-flow before being put on line, with some flowing from bottom to top, others with zones flowing from top to bottom, and data indicated from which zone the flow crossed into the other.



THERMA modeling and analysis software derives flow profile information by combining WellWatcher Flux data with reservoir, fluid, well and completion properties. It also provides Flux data visualization, such as this example from well A9 where the image shows cold fluid ingress after opening formation isolation valve, heating as the well is brought online, slight cooling progressively from the top-down as the gas displaces completion fluid, a stable production temperature and finally cooling back to geothermal after the well is shut in.

The sandface and gauge data was transmitted to Mumbai for real-time visualization and analysis. Dedicated THERMA* visualization/interpretation software was used for 3D display of the sandface data.

The power of the THERMA software was demonstrated once the wells were put online for production. Analysis of the data from the first well equipped with WellWatcher Flux data demonstrated that gas was being produced across the extent of the sandface, with no significant skin damage from invaded completion fluid. A quantitative flow profile was also obtained.

As other wells were put onto production, however, the sandface data showed something even more interesting. The data indicated that the cross-flow was not just from one compartment to another, but, often from one well to another. RIL engineers complemented this information with traditional pressure interference testing and have been able to use the cross-flow information to update their geobody descriptions in Petrel, significantly increasing their understanding of the compartments and connectivity across the reservoir. This information will be used to plan the next phase of the production drainage.

Commitment to SE Asia

According to joint RIL-Schlumberger estimates, more than 10,000 offshore and 80,000 onshore worker hours were logged during the drilling and completion phase of the KG-D6 projects without lost-time or safety incidents.

Partly responsible for giving RIL-Schlumberger project teams the ability to conduct drilling and completion activity safely, on time and on budget with timely equipment arrival and utilization has been the construction in 2007 of

WellWatcher permanent monitoring systems integrate the most advanced permanent downhole gauges with surface data communication to allow remote monitoring of wells and reservoirs in real time.

a Schlumberger Deepwater Centre of Excellence at its land base in Kakinada, India, on the coast.

Prominent features of the base include a 120-ft (36.6 m) subsea maintenance and storage tower and a 110-ft (33.5 m), 30-in. diameter test and assembly well.

There, subsea testing and completion tool strings were assembled, qualified and system-tested under realistic field conditions before being staged offshore. The Kakinada Centre serves RIL and in-country Schlumberger personnel as a training and technical support base for KG-D6 operations, as well as for similar deepwater operations for all other areas of Southeast Asia.

*Mark of Schlumberger

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