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EPRASHEED
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2014 – Issue 37

Saudi Arabia oil & gas

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Official Publication ATS&E 2014

SPE ANNUAL TECHNICAL SYMPOSIUM & EXHIBITION

April 21 – 24, 2014
Seef, AL-KHOBAR,
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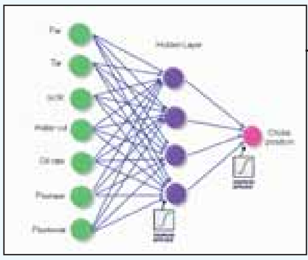
Saudi Arabia Oil & Gas (Print) ISSN 2045-6670
www.saudiarabiaoilandgas.com
Saudi Arabia Oil & Gas (Online) ISSN 2045-6689

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UNATTAINABLE UNSUSTAINABLE UNCONVENTIONAL MADE POSSIBLE

Message from the Chairman

Dear Colleagues,

On behalf of the ATS&E 2014 Organizing Committee, I am delighted to invite you to join us at the Annual Technical Symposium and Exhibition (ATS&E), which represents the flagship activity of the Society of Petroleum Engineers – Saudi Arabia Section (SPE-SAS). The symposium will take place in al-Khobar, Saudi Arabia, April 21-24, 2014.

This year's theme, "Unattainable, Unsustainable, Unconventional – Made Possible", accentuates your excellent efforts to energize the globe and deliver a sustainable future for upcoming generations. The recent advances – digital energy, unconventional resources exploitation, drilling practices and ultimate oil recovery processes – testify that our industry is reliable and can evolve to meet global demand. We encourage your participation to enhance your career growth while contributing your best ideas.

This event has grown in size, representation and importance, and is now recognized as an international platform for exchanging technical knowledge and experience among oil and gas industry leaders, experts, researchers, and young professionals. The event provides an excellent opportunity to share technical discoveries, innovative ideas, case histories, R&D projects, and new technology applications.

The technical symposium features a rich program, encompassing pre-event courses, various technical sessions, and a vibrant panel discussion. The event is also coupled with an exhibition to showcase services, products, new technologies, and best practices, which all address conventional and unconventional oil and gas challenges. The opening ceremony will involve presentations delivered by recognized leaders in the oil and gas industry.

I want to thank you all for your continued support of SPE and look forward to seeing you at ATS&E. I would also like to thank our official publication, Saudi Arabia Oil & Gas magazine.

Best Regards,

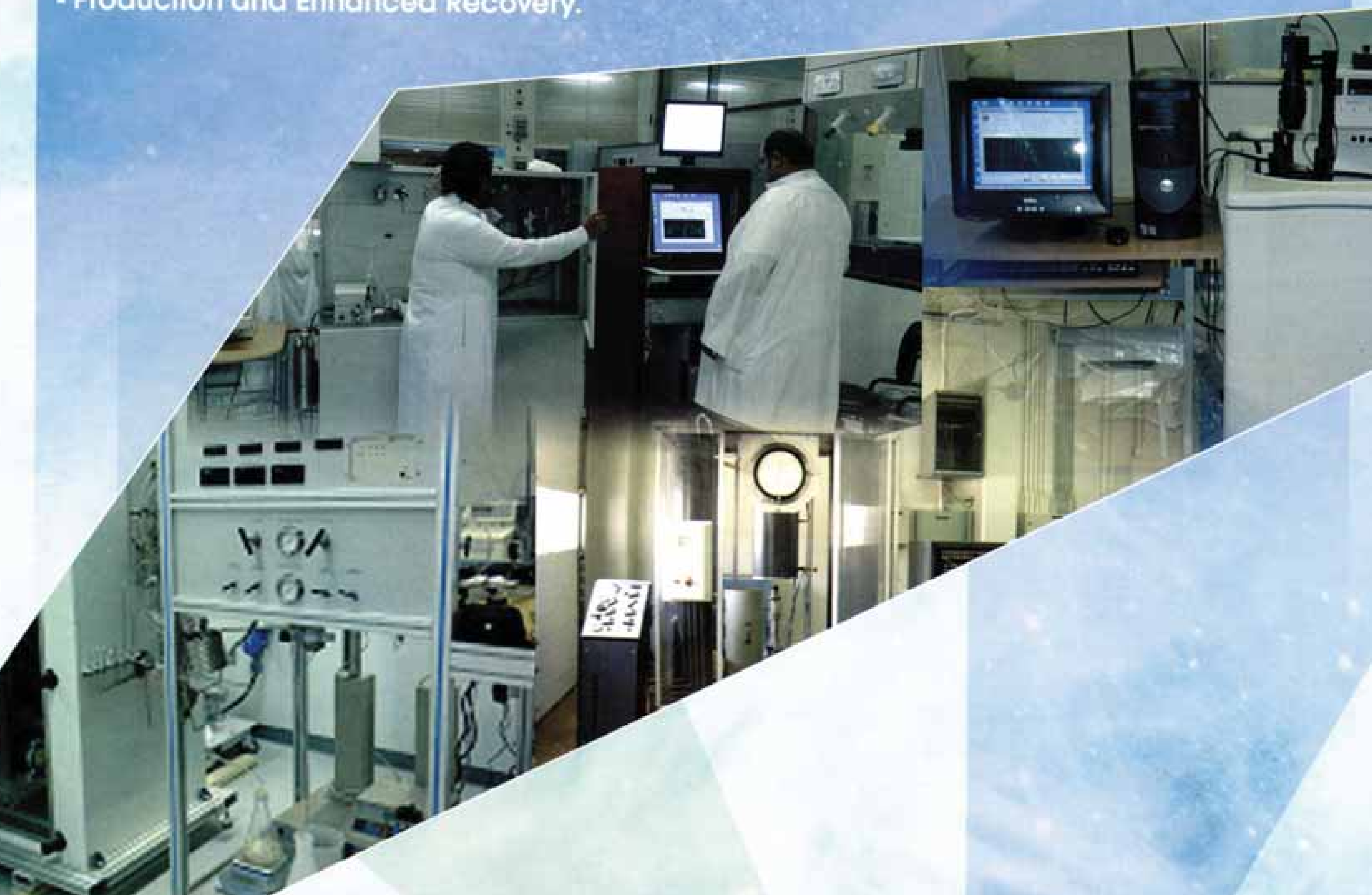
Ahmed Alhuthali, PhD, ATS&E 2014 Chairman

مدينة الملك عبدالعزيز
للعلوم والتقنية KACST

Oil and Gas Research Institute

Hydrocarbon resources (crude oil and gas) are the main source of world energy, and as the international demand increases, the technical challenges increase to meet that demand. Hydrocarbon production optimization at minimum cost and the need to serve the national petroleum industry has been the driving force behind the establishment of the Oil and Gas Research Institute (OGRI) at King Abdulaziz City for Science and Technology (KACST). OGRI is a governmental research and development entity. Its applied research activities concentrate on the upstream sector of the petroleum industry. Fields of interest cover most of the petroleum science and engineering aspects through four main divisions:

- Reservoir Characterization and Numerical Simulation,
- Drilling Engineering,
- Rock Mechanics,
- Production and Enhanced Recovery.



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YLAB Team Visits KACST

A delegation from Saudi Aramco's Young Leaders Advisory Board (YLAB) recently paid a visit to the King Abdulaziz City for Science and Technology (KACST), where an array of high-end research projects were showcased.

As the home of the National Science Agency and the National R&D Laboratories, the Riyadh-based KACST is the country's hub of applied research in 15 different disciplines, many of which are areas of focus for Saudi Aramco's own scientists.

YLAB was invited to tour the facilities by KACST president HE Dr. Mohammed Bin Ibrahim Al-Suwaiyel. As a member of Saudi Aramco's Board of Directors, Al-Suwaiyel was aware of the work in which YLAB is engaged. His first opportunity to meet some of the current and alumni members of YLAB came in December when they were asked to participate in a special session of the Board of Directors.

"At KACST, we exist to support and promote applied research, which produces technological innovations that contribute to the development of the Kingdom. That is the same goal driving the research being conducted by Saudi Aramco. There are excellent opportunities for collaboration and knowledge sharing between our two great organizations," Al-Suwaiyel said.

The YLAB members were treated to presentations covering topics as varied as international petrochemical research projects, research and manufacturing of drones for scientific purposes, water desalination using solar energy, genetic sequencing of local flora and fauna, the Sanam super computer and even a project that resulted in launching satellites into orbit.

KACST is aligned with Saudi Aramco's goal of fostering the development of a knowledge economy in the Kingdom, which, as defined by KACST, is where research and development (R&D), innovation,

> "KACST is aligned with Saudi Aramco's goal of fostering the development of a knowledge economy in the Kingdom, which, as defined by KACST, is where research and development (R&D), innovation, technology transfer and localization significantly contribute to the national economy."

technology transfer and localization significantly contribute to the national economy.

According to Thomson Reuters, Saudi Arabia had a three-fold increase in its research output in the period between 2000 and 2011, as well as a 33.1 percent increase since 2011. In 2013, Nature Publishing Index called Saudi Arabia one of the "five countries to watch".

The solutions and products that result from the research being conducted at KACST and Saudi Aramco should add or contribute to new industries that provide new skilled employment opportunities for the country's growing labor force. This, in turn, will create a more balanced economy that generates significant value from the ideas of its people just as it does from its wealth of natural resources.

Aramco Asia Springboard to Far East

BEIJING, 3 April 2014 – Aramco Asia Company consists of three companies – Aramco Far East Business Services Co. Ltd., Aramco Asia Japan Company and Aramco Asia Korea Company – and has offices in all three countries. Their existence shows Saudi Aramco's commitment to the Asian region. They offer a range of support services, including marketing oil and chemical products, investments, career development and public relations.

As Saudi Aramco continues to expand into the chemicals business, Aramco Asia provides huge opportunities for the company and its Asian partners. The region accounts for two-thirds of Saudi Aramco's oil exports.

Sulaiman M. Ababtain, president of Aramco Asia, the Beijing-based company with support branches in Shanghai and Xiamen, said, "Aramco Asia will serve as a cultural exchange gate between the Kingdom of Saudi Arabia and the Far East in addition to being a business and market information center."

China, Japan and South Korea are among the most important exporters of construction materials and services to Saudi Aramco. Such commercial transactions have contributed to the growth of the Saudi economy and helped support the growing economies in Asia.

"Establishment of Aramco Asia will help foster cooperation in the area," Ababtain said. "This step will also send a very clear message of Saudi Aramco's commitment to securing long-term partnerships in the area and its intention to stay as Asia's most reliable supplier in the future."

Saudi Aramco has huge investments in Asia, and Aramco Asia manages its shares in these investments. In China, Aramco Asia was assigned to oversee the company's interests in the Fujian Refining and Petrochemical Company and Sinopec SenMei Products Co., as well as the company's interests in two joint ventures, S-Oil in South Korea and Showa Shell in Japan.

Ababtain has more than 25 years of service with Saudi Aramco. Before his appointment as president of Aramco Asia, he was manager of Domestic Projects, Domestic Joint Ventures, Product Sales and Marketing, and Crude Oil Sales and Marketing departments, and also was vice president of Planning at Petron, then a joint venture between Saudi Aramco and the Philippine National Oil Company.

"We are confident of the steady growth of these businesses, and Aramco Asia will develop the required work plans and strategies to accommodate future growth," he said. "Growth of the Asian commercial business will contribute to achieving Saudi Aramco's strategic goal to become a fully integrated global energy and petrochemical enterprise by 2020. Moreover, Aramco Asia is planning to market other petrochemical products in Asia, such as aromatics produced in Saudi Arabia, to ensure stable client bases in the region."

The Asia region is becoming a major supplier for Saudi Aramco. "We are confident of establishing a reliable supply chain for materials and services," Ababtain said. "We have already identified more than 150 first-class Chinese suppliers for Saudi Aramco."

Aramco Asia will purchase materials to support its own offices and Saudi Aramco's businesses, as well as developing market reports on basic commodities. Aramco Asia will also identify potential suppliers, manufacturers and service providers, all the while fostering business opportunities for Saudi and Asian companies. The company also serves as Saudi Aramco's extended arm for engineering services, project management and information technology in Asia.

Despite the fact it has existed less than two years, Aramco Asia has made quantum leaps in growth. Regional partners welcomed the formation of Aramco Asia and see it as an important step to facilitating opportunities for the Kingdom and Far East.

As do all Saudi Aramco affiliates, Aramco Asia demonstrates social responsibility through strategic initiatives. The company has signed memoranda of understanding for cultural and research cooperation between Aramco Asia and the King Abdulaziz Center for World Culture on one side and prominent culture, research and intellectual houses in China, including the Chinese National Theater of Arts.

Waleed Al-Helal, Public Affairs manager at Aramco Asia, said, "The social responsibility team actively works to activate and implement Saudi Aramco's social responsibility strategies that are appropriate to social work practices in China, Korea and Japan. In China, for example, we were keen to launch social responsibility initiatives in areas where the company's joint ventures are found in Fujian."

Speaking of his public relations role, Al-Helal said, "I worked during the last months on attracting Chinese trained talents in media and public relations who have a good command of oral and written Chinese and English. The team is working in coordination with Dhahran Public Relations on developing and launching websites in English and native languages for Saudi Aramco's subsidiaries in Asia."

Aramco Asia's Marketing and Joint Projects Department plays a pivotal role in developing opportunities. The department is staffed by 16 employees of different nationalities; most are experienced Chinese nationals. In coordination with organizations in Dhahran, the department assesses new investment opportunities in Asia, ensures the crude oil needs of customers in China are met, coordinates joint venture operations administration, conducts financial analysis and economic feasibility studies, and keeps track of developments in Asian petroleum markets.

"We exert continuous effort to accelerate the implementation of investment opportunities to achieve Saudi Aramco's strategic goals to become the world's leading integrated energy and petrochemicals company," said Rakan Tarabulsi, manager of Marketing and Joint Projects.

Fiona Xanq joined Aramco Asia in January 2013 as an investment analyst. "The company cares for its employees and their family members," she said. "We also receive training courses in work fields, which require professional development. For example, I worked as an investment analyst and had no experience in oil and gas businesses. However, the company gave us the opportunity to attend conferences and training courses in this field." She noted that the work atmosphere at Aramco Asia is marked by professionalism, cooperation and a sincere desire to achieve more success for the company.

As part of Aramco Asia's operations, the Purchasing, Contracting and Logistic Services Department manages the purchase of materials and preparation of contracts, in addition to qualifying and registering suppliers and contractors. The department provides contracting services for China, Japan and South Korea. The unit's supervisor, Wail A. Al-Sahlawi, said, "Since we are still a new company, we needed considerable contracts, including contracts for expansion of offices, PR companies, establishment of the website, communication support, IT, research and development center and other contracts. This is in addition to many logistical operations, especially for transporting petrochemicals and inspection and quality contracts.

"Because we were tasked with the establishment of a new contracting unit in Asia, we had to search for competent

> "Aramco Asia will also identify potential suppliers, manufacturers and service providers, all the while fostering business opportunities for Saudi and Asian companies."

and trained local talents to process contracts according to company policy and Chinese law," Al-Sahlawi said. "I have become quite confident of the employees' intelligence, innovation, professionalism and loyalty. For example, I am impressed with the excellent performance of the three Chinese female employees working with me now. When I assign a task to one of them, she doesn't do it according to the highest professional standards only, but exerts extra effort to improve the work quality."

Karen Yuan of the Contracting Unit processes contracts. She said her work is an extension of her previous work at IBM. "After reviewing the scope of work of the new contracts required by various departments at the company, we invite interested contractors and companies to bid. After receiving their bids, we review them and award the contract to the winning company or contractor.

"As a team, we have the enthusiasm and loyalty to work with dedication. For example, we work on 16 or 18 contracts simultaneously. Even though this poses a great challenge, especially when tackling intricate details of each contract, with our perseverance and enthusiasm we manage to conclude these contracts accurately, which makes us enjoy the thrill of accomplishment," Yuan said.

Industrial Relations functions at Aramco Asia China are increasing, with responsibility for personnel in China, Japan and South Korea – handling training, maintenance, loss prevention and transportation – in short, overseeing many aspects of the employees' work and life as well as for students Saudi Aramco sponsors at Asian universities.

"We work hard to continuously recruit new employees in response to the company's business expansion, particularly in new businesses such as chemicals," said Farhan Al-Rashid, Industrial Relations manager at Aramco Asia-China. "We have contracted eight companies to provide recruitment services to help us find appropriate employees."

Al-Rashid started work in China in March 2012. "Expatriate life in China is complex; everything, searching for a residence, signing the lease, the type of foods and searching for restaurants. If an employee wants to buy a car, he has to place his name on a waiting list. … Even after receiving the car, you will receive sometimes a text message telling you that you will not be able to drive your car tomorrow or on a certain day of the week to avoid causing heavy traffic on roads."

Khalid A. Al-Radi works in the Joint Venture Coordination Department as a financial analyst. In 1998, he was sent to South Korea to learn the Korean language and started working in S-Oil in 1999. "Learning Korean is difficult."

But after learning Korean, he was able to learn more about Korean culture, which helped him understand the community and helped greatly in his work. "To understand the mentality of a person you have to learn his or her language," he said.

"I used to work in financial planning at S-Oil and later I worked in all financial and accounting departments. At that stage, I was assistant to the company's president of Finance from 2005 to 2007 and then returned to

Domestic Joint Ventures in Dhahran," he noted. "I worked for several years there, then moved in 2011 to work in the company's office in Hong Kong as head of the financial analysis team in the Joint Venture Department. After six years we were relocated to China after the establishment of the office here."

In 2012, Kamal Garatli arrived at Aramco Asia to establish a department for engineering, technical services and IT in South Korea, Japan and China. "All equipment, devices and tools must be carefully inspected. That is why we have 17 inspectors in addition to inspection companies employing more than 349 inspectors, which we have signed contracts with to perform the required work. We help them learn Saudi Aramco's specifications and standards."

The department's tasks also include establishment of a research center in China to conduct research in petroleum engineering, geophysics and geology.

"We found the location for constructing the center," he said. "Then we began searching for an engineering company qualified to execute this vital project. The company will first prepare the design, and following approvals, construction will commence."

Sirin Lu is the academic adviser responsible for Saudi Aramco's students at China Petroleum University – their studies, achievements and everyday living. There are nearly 75 students in China, Korea and Japan, and another 52 are expected to join them.

"I feel personally responsible for them," said Lu. "I am so close to them, inquire about their needs and help them solve their problems and overcome any difficulties. My work is very interesting. … Those students are the pillars who will make a difference in the future."

She said she helps students select courses and teachers and talks to faculty of the language institute or university to communicate points of views between students and the university. "Judging from experience, studying the language may take 18 to 24 months due to the difficulty of the Chinese language. Saudi Aramco's students are excellent and industrious in their educational achievement, which is gratifying. Some of them have won awards for fluency in Chinese," she said.

Hasan Al-Ghamdi, head of Aramco Asia-China Finance Division, is in charge of petrochemical sales and marketing, as well as office expenditures. In all, 24 employees work with Al-Ghamdi: six in Xiamen and 18 in Beijing, where all 18 are Chinese.

"We are responsible for adhering to Chinese tax regulations and ensuring we follow those regulations. We make sure all our accounting and tax procedures are highly accurate because mistakes or omissions are intolerable in our work."

Mahir Al-Ayadi works in internal auditing. His group provides an accurate and independent audit of the company's governance affairs, risk management and internal regulations.

"From the start of my work in China," said Al-Ayadi, "I was eager to build relations that transcend formal work boundaries to the human side, especially since we know that the Chinese people, by nature, attach great importance to friendship and acquaintance of their customs and language in processing and facilitating work. I have a wide network of relationships that have enriched my personal and work experience, and I advise my co-workers to do the same," he said.

Al-Ayadi joined Saudi Aramco in 2002 and worked in the Internal Audit Department until he was nominated to be acting chief auditor in the Fujian Refining and Petrochemical Company. He worked there from 2007 to 2012, where he contributed to establishing an audit unit. During his work in China, he obtained his internal audit certificate and is considered among the first expatriate auditors in China to receive this certificate. In April 2012, he was appointed chief auditor in Aramco Asia, where he laid the foundation for an audit department that now carries out all auditing tasks covering all of Aramco Asia's operations in China.

Sofi Chi is supervisor of Public Affairs at Aramco Asia-Beijing. Speaking about the nature of her work, she said, "My mission is to implement Saudi Aramco's public relations strategies after tailoring them to suit Chinese society, whether at work, or in social outreach with government or private entities. I also supervise employees, especially the newly hired, and try to pass my previous experiences to them. I organize visits for executives to Beijing and the company's other operation areas. I am proud of my contributions to the success of the signing of the agreement between the King Abdulaziz Center for World Culture and the Chinese National Theater for Arts and Aramco Asia."

Her work, as with all Aramco Asia employees, is strengthening the connection between Dhahran and its Asian partners.

Smart Oil Fields Infrastructure Toward Optimal Production and Real Time Reservoir Surveillance

By Karam Al-Yateem, Meshal Al-Amri, Rabea Ahyed, Saudi Aramco,Fred Aminzadeh,University of Southern California, Ahmed Althukair and Faisal Al-Khelaiwi, Saudi Aramco.

Abstract

Exploration for fossil fuels has resulted in the finding of thousands of hydrocarbon fields around the globe for over a century. During this timeframe, technology has advanced in a rapid mode with several innovation milestones in this journey. One of those milestones is the implementation of horizontal, multilateral and complex wells that require best-in-class technology to ensure control of the well for optimum production through downhole devices, such as smart chokes and inflow control valves (ICV). Lately, the concept of an "intelligent field" has been embraced by more and more operators with expectations for higher recovery from the reservoir. In addition, installation of permanent downhole monitoring systems (PDHMS) in both free flowing wells and those equipped with electrical submersible pumps (ESP) provides continuous monitoring of reservoir parameters as an indispensable tool for reservoir surveillance. Their installation eliminates well intervention data acquisition operations and reduces nonproductive shut-in time during rig-ups, which enables significant improvement of reservoir surveillance in real-time and focused utilization of resources in manpower, capital and assets.

Saudi Aramco is tackling existing problems through the utilization of technologies from smart maximum reservoir contact (MRC)/multilateral wells and mega-cell reservoir simulation to the implementation of fully integrated intelligent fields and geosteering on real-time mode, all offering a wide range of inter-disciplinary domains for development and progression. This paper will discuss the integration of smart sensory and control devices within the company's fields, deployed towards finding the optimal production strategy whether the wells are producing naturally or are artificially lifted, meeting the designated targets and providing much needed flexibility in its operations. The latter is of particular importance in fields that are located in remote areas, offshore, or near populated areas where safety considerations dictate less human intervention. In addition, effective methodologies of data mining and computational modeling are necessary to attain these goals. Such methodologies are effectively placed to ensure the best utilization of integrated

operations, as well as to obtain accurate and useful data flow paths. In a nutshell, the implementation of technological advancements result in a positive impact on field performance in a real time fashion, extending the producing life of wells, harmonizing sweep efficiency and ultimately maximizing oil recovery from the fields.

Introduction

Since the intelligent field concept started in 2003, operating companies worked to enable such capabilities through various technology deployments, both in the field and at the offices. Saudi Aramco, in particular, had the challenge of deploying these technologies in new projects and existing infrastructure alike. With the tremendous responsibility given to the company and a continuous promise always to deliver according to global needs, applying intelligent field methodology proved to be the best way.

This paper focuses on the Saudi Aramco approach over the past 10 years and how an intelligent field helps to manage, deliver, optimize and develop short- and long-term decisions and plans.

Evolution of Smart Complex Projects

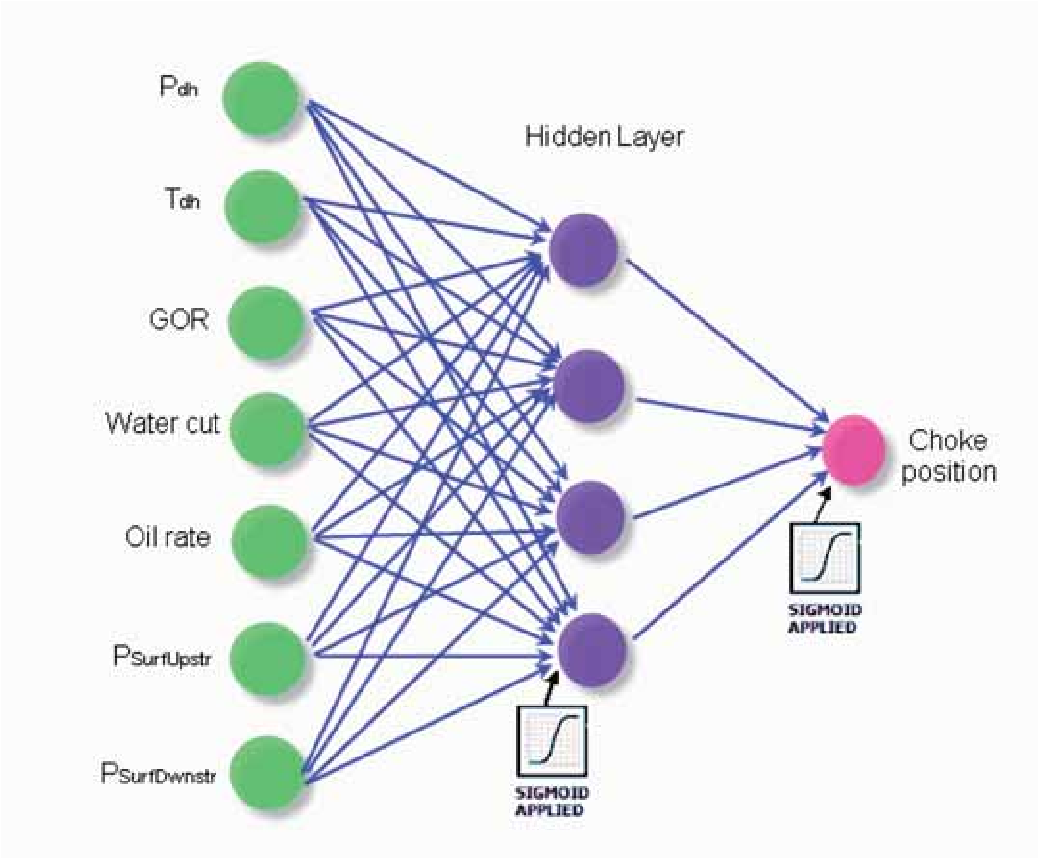
Existing Fields

The main challenge with existing infrastructure is how to combine and integrate older systems into a newer one. Upgrading can be both expensive and time consuming, as it could disrupt or off-balance production and performance at the time of construction.

With carefully calculated and coordinated planning, many wells were upgraded with smart inflow and monitoring equipment, which included sidetracks with inflow control valves (ICVs) and permanent downhole monitoring systems (PDHMS) in addition to electrical submersible pumps (ESPs) with downhole gauges. Surface equipment was also installed in place to communicate with existing supervisory control and data acquisition (SCADA). Several upgrades to the SCADA systems were also made to get these tools up and running.

New Fields

In this case, the deployment methodology lies within the planning phase of the project. Deploying intelligent field equipment – both downhole and at the surface – was successful in all projects starting with three major oil fields in Saudi Aramco's Northern Area. Mega-projects on such a scale can best utilize the intelligent field capabilities as the effect is seen across the different levels of production starting from the reservoir level, up to the completion, and across the surface pipes and processing facilities. This integration also enabled further improvements and streamlining,which will be explained later in more details.



Intelligent Field Clusters

Saudi Aramco intelligent field development structure consists of four major layers as shown in Fig. 1, namely Surveillance, Integration, Optimization and Innovation. The surveillance layer provides continuous monitoring of production information and applies data management tools and processes to ensure usefulness of the data. The integration layer interrogates real time data on a continuous basis to detect reservoir behavior trends and anomalies. Reservoir engineers are alerted to such anomalies for further analysis and resolution. The optimization layer provides streamlined full field optimization capabilities and field management recommendations. The innovation layer preserves knowledge of events that trigger the optimization process and corresponding actions throughout the life of the field. This is a knowledge management and lessons learned layer that captures and injects "intelligence" into the system. Following are the objectives and a brief description of each layer.

SURVEILLANCE

ICVs/PDHMS/MPFM

Application of downhole valves experience: The first implementation of these completions in Saudi Aramco took place in conjunction with maximum reservoir contact (MRC)/multilateral wells in early 2004. Encouraging results from the MRC/multilateral wells triggered the need to optimize and manage production from different laterals. This need was translated into piloting downhole ICVs.

Approval of the ICVs concept was achieved when the anticipated benefits were realized by monitoring the actual performance of these wells. The leveraged knowledge has provided an insight into ICV capabilities and implementation. Moreover, it has set the stage for the development of a major oil field exclusively with MRC wells equipped with ICVs. The concept has not been limited to new wells. ICV utilization has extended to enhance performance of existing weak and dead conventional wells after converting them to MRCs and multilaterals. The technology even extended to targeting single lateral new horizontal wells where downhole valves were installed across the horizontal section. Moreover, the good results have invoked trying new downhole technologies, such us permanent downhole multiphase flowmeters (MPFM). In one trilateral well, every downhole valve was combined with MPFMs and permanent downhole pressure and temperature gauges. The latest technology was tailored to target existing dead wells where slimhole multilaterals and single laterals were drilled and equipped with downhole valves across their openhole sections.

ESP Sensors

In addition to the PDHMS used for freeflowing wells, ESP sensors are utilized in all oil wells installed in Saudi Aramco. These sensors provide the data required for production rate measurements as well as direct measure of ESP parameters to protect the ESP. It further helps to get real-time measurements of the reservoir pressures and temperatures, which satisfies the surveillance requirements for these fields.

Real-time Network

• Drilling: Geosteering is widely used in the company as more challenging reservoirs and projects are developed. Real-time data from both onshore and offshore rigs are transmitted directly to Saudi Aramco's geosteering center (which will be detailed later). This direct decision making enabled crucial actions to be taken exactly when required, mitigating nonproductive rig time. The effect of such a system impacts both the short term objectives, such as rig drilling directional plan fulfillment and also maximizes reservoir management and control for the lifetime of the field.

• Monitoring: An essential part of production is the ability to "listen" to the reservoir and wellbore. Manual data collection through well intervention opens only a small window into the reservoir as it captures instantaneous readings. With real-time capabilities, monitoring helps engineers across the company to understand the behavior of the field, which gives a great advantage for better usable data analysis. Whether the well is flowing naturally or equipped with gaslift or an ESP, this ability mitigates many potential failures, protects company assets and prolongs the life of the field.

• Remote Control: The second level of monitoring is control. Remote control is applied in several fields in Saudi Aramco for both downhole and surface valves, for example. Such capability greatly improves the production and testing efficiency. This saved the company countless working man-hours and opened the doors for better field optimization.

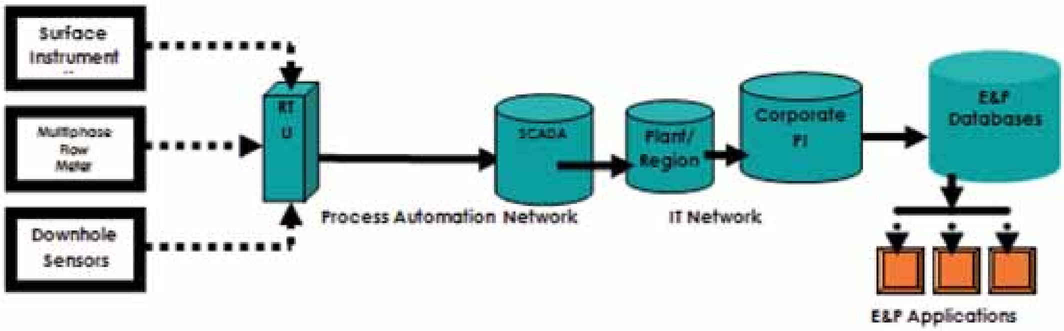
Data Quality Control

Soft computing is an efficient and effective method of data mining. It provides real environment optimization of operations, ultimately leading to the appropriate selection of best-in-class technology deployment in a field, and therefore sustains the field's production level, prolongs the life of wells and controls the wells for optimum production. The application of soft computing in the E&P industry assures leaving the least amount of oil in the ground (increase production), finds every economic barrel yet to be discovered (cut cost) and expands the recoverable resources (accelerate recovery). Additionally, the outlook hydrocarbon price supports the application of such technologies. It is a long-term investment that will improve reliability, reduce reentry and its cost, improve decision making, reduce human intervention and provide rapid response to market conditions.

Remotely operated MRC/multilateral wells with smart well completions have reduced the well count, increased productivity, improved flood front conformance while lowering water production and reduced overall operating costs. Subsequently, the latest advancements of soft computing (utilized to diagnose production problems and set appropriate solutions in Middle East fields) still requires an operator to remotely control the downhole valves through a SCADA system.

Neural Network (NN) is an artificial network that simulates the behavior of a human biological network of neurons by assigning weights to connections between layers of neurons to suggest a degree of influence. Figure 2 is a basic structural overview. They can be used through SCADA to test the individual zones of smart MRC/multilaterals wells and therefore eliminate continuous operator supervision and decision making. This requires building a network that connects to the SCADA, receives well data and makes decisions using a NN system for choke positions through the SCADA application. Operator free full automation of intelligent well downhole control will further reduce operating costs, eliminate the constant supervision of SCADA application, achieve better and faster decisions via the network's ability to continuously train and learn instantaneously through real-time data feed after flow tests. They accelerate production and optimize performance with the best usage of the intelligent facilities.

Initially, the NN could work as an alerting mechanism or warning system for a stringent set of parameters defined for the reservoir. It would perform soft computing on the continuous stream of data from the instruments. The system would summarize data from multiple well PDHMS and other downhole



instruments; however, the uncertainty in the reservoir flow characteristics between wells would be unknown and would change the decision making process for the production engineers. Monitoring rules are continuously altered in a producing reservoir based on production history and diagnostic measurements. The data needs to be fed into a reservoir fluid simulator for spatially defining the flow characteristics, and therefore are used for updating the monitoring rules. This will perform like a virtual advisor with artificial intelligence and provide advisory messages.

The alerts could be in the form of "insufficient pressure support over an area," "sweep efficiency below target," "water cut increment rising abnormally," "condensate accumulation becoming critical" near the wellbore, etc. The alerts would provide scheduling action plans for the field engineers in optimizing the well production.

In the future, more advanced application of soft computing for NN would provide a total automation in real time management of reservoir fluid production and injection processes in multilateral wells. Reservoir and production engineers would monitor the performance of the system and would have the capability to override the automatic system and vary the parameter settings to affect the overall reservoir performance.

INTEGRATION

Advanced Reservoir Simulation Models

Saudi Aramco has the state-of-the-art simulation model GigaPOWERS. This new generation of the POWERS reservoir simulator became official in 2008 as the industry's first billion cell simulation model. A full field model of a major oil producing reservoir was used to conduct this industry record achievement. The simulation model was comprised of 1.8 billion active cells, a real grid size varying between 15m to 20m (sub-seismic resolution), average vertical layer thickness of 3.7ft and included 117 vertical layers.

As new and approved reservoir data streamlines from the field, the specific model of the reservoir is updated to allow better short- and long-term planning. This model was specifically built for Saudi Aramco and has tremendously improved our prediction.

Surface and Subsurface Integration Software

Modeling and forecasting software was also used for the wellbore and surface lines. Covering this section with real-time data enabled a quick response to problems and helped pinpoint failure points when troubleshooting or determining the bottlenecks within the company's infrastructure.

The existence of these systems enabled the company to move forward to the Optimization and Innovation clusters within the intelligent field structure.

Intelligent Field Data Acquisition and Transmission

Saudi Aramco's intelligent field initiative has established a new set of requirements to meet increased demand on data in terms of accuracy, update frequency and validity for existing and future oil fields. This section shows how Saudi Aramco establishes recommended methodology and defines the additional functionalities required to fulfil the data acquisition and transmission during normal operation and during system or communication failure(s), Fig. 3.

Saudi Aramco has put more focus on the health of intelligent field data by forming a communication standards committee to thoroughly look at the best-in-class practices in the data acquisition with minimal data loss. This has been accomplished by establishing an intelligent field data acquisition and delivery requirement, which includes the following:

• All real-time data delivery systems should be available 24 hours per day, 7 days per week.

• Data delivery reliability should be 99% for visualization and 99.9% for all altering and alarming.

• Data collections frequency should meet intelligent field requirements.

• Data should be backed up at all levels. There should be no data loss due to system downtime and all data should be recovered upon problem resolution.

• Problem resolution time should be no greater than 4 hours.

OPTIMIZATION AND INNOVATION

Streamlining: Collaboration Centers

Realizing the significant impact on decision making, Saudi Aramco has expended enormous effort to establish collaboration centers that capitalize on large-scale, multidiscipline, value-added technical and business collaborations. A collaboration center is defined as a permanent and dedicated physical space utilized by a team working to fulfil a common and often complex, time critical, study objective. It is not a temporary location, nor an adhoc initiative. It is a high impact (safety and business critical decision making) company asset that undertakes multiple, and generally, parallel activities, including data retrieval, data validation, model building, simulation, prediction, production optimization, well intervention and operational development decision making. Saudi Aramco's collaboration centers provide the means to deliver high-level technical and business improvement in specific work tasks, including exploration, geosteering, drilling, intelligent fields, optimized field development, and advanced skill-set development. Accordingly, Saudi Aramco has realized, developed, and experienced a number of industry leading technology, process, organizational, operational, and technology support benefits that would not have otherwise materialized without the foresight to adopt and use the following collaboration facilities.

1. *Geosteering Operations Center (GOC):* One of Saudi Aramco's first collaboration facility centers. Established in 2005, the GOC provides operational expertise to monitor, analyze, and model the optimal placement of horizontal and multilateral wells for MRC. Designed to concurrently monitor up to 75 drilling rigs, the GOC is equipped with a broad spectrum of industry leading software, hardware, and visualization technologies. The GOC, as a round-the-clock facility, actively monitors thousands of feet of drilled reservoir section on an annual basis, including the complex time consuming analysis of a large volume of real-time data, e.g., measurement while drilling (MWD) and logging while drilling (LWD), feeds on a minute-by-minute basis.

2. *Exploration Operations Room:* Established in 2006, this group provides centralized wellsite geology expertise for strategic exploration and development projects. Equipped with industry leading field and office geological technologies, the EOR monitors and provides real-time decision analysis, e.g., formation evaluation and mud logging, of key exploration and development well decisions, including casing-point, coring, and drillstem test selection, in addition to centralized daily well reporting andwell decision management.

3. *Real-Time Drilling Operations Center (RTOC):* The RTOC provides centralized drilling operations expertise to lower and quickly resolve nonproductive drilling related incidents such as stuck pipe, borehole instability, tight hole, etc. Established in 2008, this 24/7 facility can support more than 40 concurrent drilling rigs. The RTOC is equipped with a wide spectrum of world leading analysis techniques and technologies to efficiently consume, analyze and model a large volume of real-time, e.g., MWD, LWD, directional, drilling fluids, temperature, pressures, etc., data feeds in favor of improved and time critical well management decisions.

4. *Event Solutions Center (ESC):* Saudi Aramco established the Event Solution collaboration facility in 2006 to undertake major multidiscipline optimized

field development plans (OFDP). It distinguishes itself by completing complex projects in weeks rather than in years with increased clarity on uncertainty, optimization and risk mitigation. Facility deliverables include best-in-class OFDP workflows and technology innovation through synergized reservoir characterization, reservoir understanding, simulation and modeling.

5. *Intelligent Field Centers (IFC):* The IFCs are an integral component of a large field and well instrumentation and automation initiative. Inaugurated in 2009, two intelligent field collaboration facilities provide a dedicated work environment for management and technical experts to remotely view, analyze, model and initiate reservoir production (well and field level) optimization decisions. Located at Saudi Aramco's Dhahran headquarters, these facilities provide the opportunity for multidiscipline professionals to access and contribute to critical well and field reservoir optimization decisions from the desktop in real-time.

6. *Upstream Professional Development Center (UPDC):* Meeting future energy demand is a cornerstone of Saudi Aramco's upstream operations. The challenge of meeting this demand is growing more complex. To meet this demand and to remain the world's most reliable supplier of petroleum energy requires new skills, new knowledge and new ideas. The UPDC is designed to equip the next generation of petroleum engineers and geoscientists with the skills they need to meet future challenges. The center also serves as the knowledge transfer bridge connecting our senior professionals with the new generation of employees. The center's mission is to ensure a sustainable, competent Saudi Aramco upstream workforce by providing effective and efficient professional development for all upstream professionals.

Conclusions

Intelligent wells and completions have been around for 10+ years; the number of installations has been growing fast around the world and is estimated to be in excess of 900. Many National Oil Companies (NOCs), International Oil Companies (IOCs), Educational Institutions and Service Companies are investing time, money and effort toward the intelligent field.

Benefits of smart completions in an intelligent field can be only realized fully with a central facility that would have control on all ICVs, soft computing that will provide a collaborative environment for expert scientists and engineers to remotely control all installed systems. The collaboration will allow individuals from various disciplines to track changes and detect errors. A mission control center would be appropriate for real-time control and realization of strategic business decisions.

1. Utilization of intelligent wells has been extended to enhance performance of existing weak and dead conventional completion wells after converting them to multilaterals.

2. ICV and other smart equipment provides flow control of commingled production from different laterals; manages production in real time to optimize oil performance.

3. Field performance indicates smart wells are consistent with meeting reservoir production and injection objectives, such as sustaining productivity, improving sweep efficiency, managing water production and minimizing production interruptions. Once a well starts producing water or gas, the production is managed by changing downhole valve positions to eliminate undesired production.

4. The effectiveness of intelligent completions is improved by the careful planning, design and placement of laterals.This can be accomplished using geosteering technology.

5. Soft computing would allow assimilating the large amounts of test data, rapidly forming production parameters and making reservoir decisions quickly and more consistently.

Acknowledgments

The authors would like to thank Saudi Aramco management and the University of Southern California for permission to publish this paper.

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Smart Calliper for Measurement While Drilling

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Abstract

This paper outlines the R&D methodology, accelerated testing and successful results of an innovative Smart Reamer Calliper for measurement while drilling. The concept was progressed from design to prototype with long hours downhole drilling qualification tests completed in 3 years. Limitations often exist with ultrasonic calliper measurement technology due to bottom-hole assembly (BHA) placement and changes in fluid density. The Smart Calliper prototype tool overcame these limitations by building on-board proper calibration and multiple sensors that allow 360° mapping of the wellbore shape. Further optional Measurement While Drilling (MWD), vibration, magnetic and underreamer position sensors can be added.

An R&D project was established with incremental tests identifying root-cause failure/design issues before moving to the next stage. This iterative process ensured proper prototype manufacturing and minimized risk at critical test points. At the same time parallel activities enabled the project to reduce overall time associated with common project tasks. The whole R&D consisted of four stages: design and finite element analysis (FEA), small scale testing, full scale testing and long hours of field test drilling.

The prototype tool was first tested in sliding, rotating and underreaming BHAs for drilling a total of 900 m in chalk, clay and sands. Small scale lab tests – including high pressure and temperature at 13,053 psi and 150°C for 100 hours – were conducted in England. Full scale under-reaming testing occurred in Norway with a wireline calliper for cross-check of the wellbore diameter measurement, and finally another qualification test in England comprising 59 hours on bottom drilling.

Last, a real-time data display was performed via an integration with a standard mud pulse telemetry. In conclusion, the new Smart Calliper tool accurately measures and can provide both memory and real-time data of the 3D wellbore, allowing the drilling team at the rig-site to:

- Pinpoint narrow or under-gauge wellbore sections, verifying underreamer performance and measuring wellbore diameter above the reamer, allowing for a corrective reaming trip to be performed while drilling BHA is still in hole.
- Offer better cement volume estimate to minimize excess.
- Eliminate wireline calliper deployment.
- Eliminate a wiper trip typically carried out prior to running long casing or liner string.
- Offer monitoring of downhole tool vibration and separate directional survey if required.

Introduction

The project goal was to develop and field test a prototype for oil and gas drilling, and certified by end user customers according to stated criteria. Certification criteria were pressure, temperature, shock, vibration, durability and component life with minimum on bottom drilling hours.

If proven successfully, the technology and field services, provided by UK based Smart Reamer Drilling Systems Ltd., would be deployed commercially in the field and lead to a new downhole drilling tool system that would save rig operating time and hence reduce well cost for operators. This patented technology consists of ruggedized printed circuit board (PCB), software, sensors and appropriate steel housings.

The initial major challenge was making the lab/workshop technology suitable for field use. To overcome this, the project focused on de-risking the system at each stage by working closely with customers and suppliers to build confidence and certify the tool for commercial use.

R & D Methodology

The R&D methodology adopted a classic stage-gate approach based on three major stages. The first was proof of concept in 2007. The second was further research and development in 2009, and the third stage was the verification of the downhole prototype 2011. This final stage sought to seamlessly integrate all the lab tested components of the Smart Calliper tool into a rugged steel housing and surface decoder already proven for standard oil and gas drilling. To successfully overcome this lab to downhole drilling challenge, the approach tested the Smart Calliper tool in discrete and incremental stages. Consequently, the root cause of any problem was isolated and resolved before the next test occurred. In this way, the staged tests built confidence and progressively certified the tool for field qualification tests and later for commercial use.

The project was supported by Saudi Aramco and another major operator and Technology Strategy Board UK. The project was split into four stages and eight work packages, with a view to accelerate the making of a prototype. It was led and managed by Smart Reamer Drilling Systems Ltd. UK, with qualification test requirements provided by Saudi Aramco. A detailed Gantt chart with costs, responsibilities, tasks, durations and contingencies was drawn up and updated as the project progressed.

Extensive customer and supplier input ensured that the development prototype would be fit for purpose. Working closely with customers ensured the technology meets field requirements and a complete testing schedule will certify the prototype for commercial use. Working closely with suppliers ensured each detailed work package would meet field requirements and is manufactured cost-effectively.

Tool tests culminated with drilling in several wellbores, selected in conjunction with our customers who provide part funding, performance criteria and witnessing of the Smart Calliper tests to handle the following:

- Pressure and temperature.
- Drilling shock and vibration.
- Minimum component life.
- Mechanical stress and loading.
- Changes in drilling fluid density.
- Changes in wellbore roughness and lithology.
- Data transmission and protocols.

To transition smoothly from the lab to downhole, each stage concluded with a full reporting of the physical tool condition, real-time data quality and an emphasis on redesign and rework as required:

- Stage 1 – Planning: Compliance with Health, Safety, Environmental (HSE) standards and Field Operating Requirements.
- Stage 2 – Tests: Low Pressure/Low Temperature (3,000 PSI and 75°C).
- Stage 3 – Tests: High Pressure/High Temperature (12,000 PSI and 125°C). Pressure and temperature cycling replicates the harsh downhole conditions and is split for two reasons. First, if the tool works only in the low pressure/temperature environment, this allows some commercial usage. Second, if the tool were to fail at the higher temp/pressure, the root cause could be identified and changes specified as required. By testing the entire system to both high pressure and temperature, the integrity of the technology will be tested for over 100 hours. This test data refined the prototype and ensured it worked before a full-scale drilling test at a rig.
- Stage 4 – Drilling Tests: Measurements while drilling included comparison with an independent multi-arm mechanical calliper, to verify the correct reading of the Smart Calliper and real-time streaming to the surface.

Tool Development and Project Management

Risk mitigation is critical to new downhole tool development and has been a guiding philosophy for the project. The strategy of the research project has reduced the fundamental risk from a lab point of view. Subsequently, each risk type has been assessed according to its importance and mitigated systematically as per the risk table. As a standard method of minimising risk we used modelling and finite element analysis to pinpoint critical areas and corrected any design errors before cutting steel and housing sensors. We also made extensive use of the proven and well established suppliers in the oil and gas or their speciality area.

The project was implemented as follows:

- The creation of an experienced project team with a track record of downhole technology development. Both the company and the end-user had assigned staff who had already developed drilling and logging tools.
- Materials supplied by long established premium oilfield suppliers. Quality control and component tracking

Figure 1. Smart Reamer Calliper tool (8 5/8” OD, silver color) made-up above Rhino Reamer (open to 14”).

lowers risk and progressive testing as per Gantt and will provide input for redesign and review after each stage.
• Rugged steel body was compliant with industry standards. The steel is high grade, which has high tensile and compressive strengths and is proven in drilling applications.
• Low drilling risk slick design, no moving parts, no pressure drop requirement, and no internal diameter restriction.
• Lab version being functional, full end-user support and use of existing suppliers.
• Patents granted in international jurisdictions for various drilling and underreaming applications.

The project team was responsible for the prototype verification and achieving the four key project milestones. The majority of the project team was based in the UK but the project involved four different countries comprising separate companies. Therefore, it was vital to be able to successfully maintain communication and cohesion within the team to achieve the required objectives. The team had already successfully managed the previous conceptual and research project and was best placed to transition to the downhole prototype. The continuity of R&D purpose allowed the team to make long-term decisions while remaining flexible to changing needs such as re-design and re-test. Close working relationships with customers and existing suppliers increased the probability of a verified fit for purpose prototype.

A Gantt chart detailed the project duration of 18 months with the project deliverable concluding as to whether the Smart Reamer can accurately measure wellbore diameters in a downhole wellbore.

Various FEA models were run to enhance the existing design and involved the location of variables and numerical values to determine fatigue, resistance and infinite wear in specific sections according to standard drilling parameters such as torque, compression, tension, bending moments, etc.

The project team generated a final report with conclusions and de-risks the prototype so before the first commercial test there will be sufficient confidence in the performance of the Smart Calliper in a real drilling environment. Customers will provide relevant well data, operational requirements and field usage in the future.

Therefore the Smart Calliper project has been geared toward practical field applications and based on actual operating parameters. Consequently, it is estimated that the operator may save 24 hours of rig-time per usage or more depending on the application.

Static Temperature Tests

The Smart Calliper electronics (i.e., operating PCB and wiring) were placed in an industrial Memmert temperature controlled oven in compliance with HSE and environmental considerations. Attached to the PCB was a thermocouple with separate temperature display to the oven which ensured the correct operating temperature of the PCB was recorded. External connections to the PCB consist of a transducer immersed in a mud sample of oil based mud at 14 pounds per gallon with a sandstone reflector. The power supply was a low voltage using a suitable communications interface connected to a computer running Smart Reamer recording software.

An initial calibration test was undertaken in the Laboratory before equipment was moved to the test facility for the 100 hours test. The equipment was checked and calibrated at ambient to ensure correct operation. The transducer was located in the mud at a fixed distance from transducer face to reflector. The temperature was continually raised to 150°C and run for a total of 108 hours over the period being cycled off every 12 - 14 hours. The temperature testing was important to ensure there were no adverse consequences of electronic components suffering from infant mortality and creating functional limitations. The sonic velocities were also observed as per the temperature cycling and gradient.

Static Pressure Tests

The Smart Calliper (i.e., mechanical housing, sensors and other components) were set up for pressure testing in a 15” pressure vessel in compliance with HSE and environmental considerations. The comprised connected a data cable, which would allow for the pressure in the vessel to be continuously monitored by the data logger. This would be important to identify if any pressure breach were to occur. The housing was lifted into the vessel using an overhead crane and the pressure ramped up to 13,053 psi was applied. The pressure was traced via a transducer and the record transmitted as an output from data cable. The testing was conducted initially for 24 hours continuously and the housing retrieved and inspected before returning to continue the test for a further 75 hours.

The pressure test allowed for the direct assessment of all housing components, seals, sensors and mechanical parts. An initial calibration test was undertaken in the laboratory at slightly above ambient pressure before

BHA #1 12 1/4" Bit and Near Bit Reamer			
1	12/1/4" bit	12 1/4	
2	Bit Sub	1.24	8 1/8
3	Near bit Reamer	6.04	11 1/8
4	XO	7.29	8
5	Saversub	8.39	6 1/4
6	Smart Reamer Calliper	10.6	8 5/8
7	Saver sub	11.85	6 1/5
8	XO	12.85	6 7/8
9	Pony DC	14.9	8
10	12 1/8" Stab	16.8	12 1/8
11	Pony DC	18.8	8
12	XO	20.8	8 1/8
13	6 1/2" Jar	32.69	6 1/2
14	5" Drill Pipe 19.5# S135		

Table 1. BHA with near bit reamer.

equipment was moved to the test facility for the 100 hours test. The Smart Calliper housing and components, as well as the pressure vessel, were checked and calibrated at ambient after the test to ensure correct operation.

Drilling Tests at Wells 1 and 2

In the first set of required drilling tests, a total six runs were conducted, incorporating the Smart Reamer Calliper during field drilling tests in Newbury, Oxford, UK. The tested tool size was 8 ⅝" OD (4 ½" IF connections) in the varying sizes of BHA, increasing from 9 ⅞" to 12 ¼" and 14". If it were proven that the smaller tool could take measurements in a large hole, this would add confidence to the overall ability of the Smart Reamer Calliper to function in larger hole sizes. This would help provide operators with a fit for purpose solution that would be an improvement on existing acoustic callipers, both in measurement range as well as standalone flexible BHA placement. These tests were successful in drilling in 9", 12 ¼" and 14" hole in consolidated limestone with highly abrasive flint stringers. Total footage drilled was 100 m and provided confidence prior to mobilizing equipment to Norway for further drilling tests.

Well 1 – Run 1/Run 2/Run 3/Run 4. The formation was a low lying chalk with quartz inter-bedded brittle shale and quartz. In total four runs were performed in hole diameters varying from 9 ⅞" to 12 ¼". The BHA runs comprised a pilot hole drilled using a PDC insert bit of 8 ½" series and 9 ⅞" series with the pilot hole subsequently opened to 12 ¼" by near bit reamer, as Table 1. The Smart Reamer Calliper was run as a standalone Calliper both with and without modular full-gauge and undergauge stabilization in all the pilot and enlarged holes providing verification of the pilot and enlarged hole sizes. The Smart Reamer Calliper was also configured with calibration sensors enabled to detect changes in density and these were recorded. The pilot hole BHA was also run slick while the enlarged hole was run with stabilized BHA using 12" stabilizers

BHA #1 12 1/4" Bit			
BHA	**Component**	**Length (m)**	**Gauge/OD**
1	12/1/4" bit	12 1/4	
2	Bit Sub	1.24	8 1/8
3	Pony DC	3.04	8
4	12 1/8" Stab	5.13	12 1/8
5	Pony DC	7.15	8
6	12 1/8" Stab	9.35	12 1/8
7	Pony DC	11.5	8
8	XO	12.73	8
9	Saversub	13.65	6 1/4
10	Smart Reamer Calliper	15.89	8 5/8
11	Saver sub	16.81	6 1/5
12	XO	17.88	6 7/8
13	Pony DC	19.9	7 7/8
14	12 1/8" Stab	21.89	12 1/8
15	XO	23.12	8 1/8
16	6 1/2" Jar	32.69	6 1/2
17	5" Drill Pipe 19.5# S135		

Table 2. BHA without underreamer.

BHA #2 12 1/4" Bit with Underreamer			
BHA	**Component**	**Length (m)**	**Gauge/OD**
1	12/1/4" bit		12 1/4
2	Bit Sub	1.24	8 1/8
3	Pony DC	3.04	8
4	12 1/8" Stab	5.13	12 1/8
5	Pony DC	7.15	8
6	12 1/8" Stab	9.35	12 1/8
7	underreamer	14.4	11 1/2
8	XO	15.63	8
9	Saversub	16.55	6 1/4
10	Smart Reamer Calliper	18.79	8 5/8
11	Saver sub	19.71	6 1/5
12	XO	20.78	6 7/8
13	12 1/8" stab	22.77	12 1/8
14	XO	24	8 1/8
15	6 1/2" Jar	33.57	6 1/2
16	5" Drill Pipe 19.5# S135		

Table 3. BHA with underreamer.

with 6 ⅝" REG connections and 10.8 pounds per gallon water-based polymer mud. Operational parameters such as surface rotational speed, torque, vibration, pressure, pump rate, flow rate, weight, etc., were recorded along with the penetration rate.

Well 2 Run 1/Run 2. In total two runs were performed in hole diameters varying from 9" and 14". Drilling comprised a pilot hole drilled using a PDC insert bit 9 ⅞" series, with the pilot hole opened subsequently to 12 ¼" by a near bit hole opener. The pilot hole BHA was run slick and the Smart Reamer Calliper run above the reamer in the enlarged hole with stabilized BHA 12" stabilizers and hole opener with 6 ⅝" REG connections and water-based mud (environmentally friendly polymers 10.8 pounds per gallon). Additionally, in this test the vibration and cutter block positions and magnetic position sensing were recorded by the Smart Reamer modules. The data from the wellbore measurements, block position and vibration were processed and compared to provide a comprehensive set of wellbore measurements and verify the hole opening. Operational parameters such as surface rotational speed, torque, vibration, pressure, pump rate, flow rate, weight, etc., were recorded along with the penetration rate.

Drilling Tests at Well 3

As part of the project, the Smart Calliper tool system was required to be tested during open hole drilling and under-reaming in Test Well C1, Ullrigg of IRIS, Stavanger in Norway. This test well was chosen because it offered the industry standard infrastructure for full-scale drilling tests (similar to a typical onshore drilling rig) and characterizing the Smart Calliper without risking live well operations. The drilling test successfully met the objectives detailed below without any downtime.

Well 3 test objectives were to establish the accuracy and range of Smart Calliper measurements in variable size holes by comparison with a wireline calliper.

1. To measure and image the surface riser to the 13 ⅜" cased hole.
2. To measure and image the 12 ¼" open hole from 38 to 58m MD.
3. To measure and image the 14" under-reamed hole from 44m to 50m MD.
4. To record comparative cutter block position and calliper in the under-reamed interval.
5. To compare all measurements with a 6 arm wireline calliper.
6. To identify and rectify any failure modes by inspecting tool and system components for wear or damage caused by vibration, shock or flow.
7. To measure changes in mud density and their effect on speed of sound using built-in calibration.

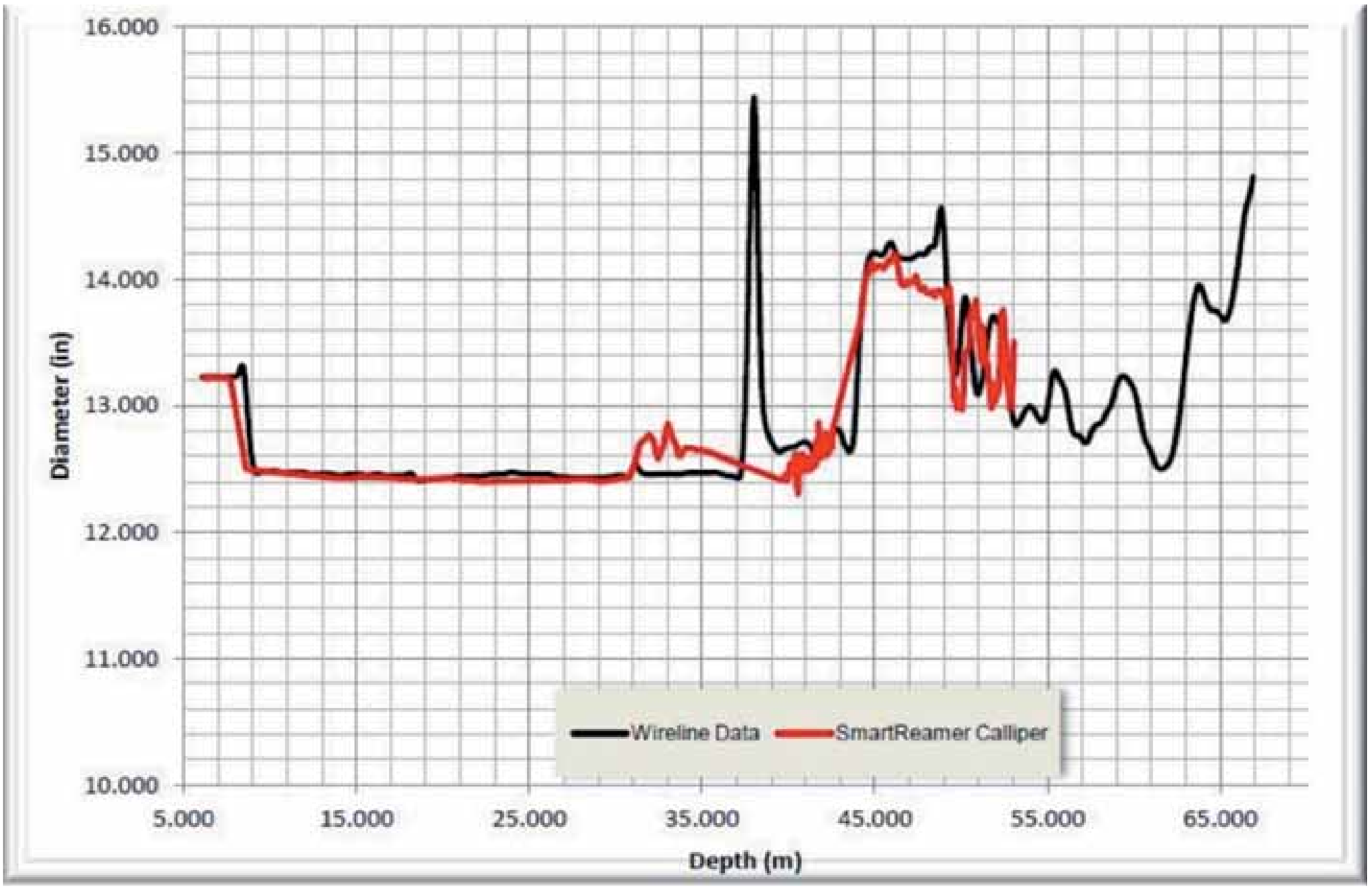


Figure 2. Comparison of calliper data in test interval.

The tested Smart Calliper tool size had an 8 ⅝" OD (with 4 ½" IF connections) and the smallest OD component in the 12 ¼" BHA (see Fig. 1 and Tables 1-3 for BHA make-up components). If it were proven that the smaller tool could take measurements in large hole, this would add confidence to the overall ability of the Smart Calliper to function in larger hole sizes. As with previous tests, this would help provide operators with a fit for purpose solution that would be an improvement on existing acoustic callipers, both in measurement range as well as standalone flexible BHA placement. The operator project manager was present at the tests and this proved very useful in providing operational input and witnessing the operation.

Multiple runs were performed in hole diameters varying from 12 ¼", 13" and 14". Drilling comprised a Smith Gemini series 12 ¼" Tricone bit with Rhino Reamer and 12 ⅛" BHA stabilisers with 6 ⅝" REG connections using fresh water. The formation is a low lying Muscovite with quartz inter-bedded graphite, granite, brittle shale and quartz, with typical strong to very strong characteristics with uniaxial compressive strengths ranging from 50-250 MPa.

Test Procedure

The Smart Calliper tool was surface programmed to measure wellbore diameter and take wellbore measurements upon rotation only. This is a user defined parameter and rotation is not necessary for measurements and can be based on other parameters.

Additionally, in this test scenario, it was useful to mark the time and number of rotations, which provides a clear reference point for measurements to start and stop. The flexibility of the modular system is such that measurements can be taken independently or simultaneously. For example, in the tests, the calibration measurements were recorded independently of the calliper but were available for processing on demand. It should be noted that the measurement of vibration also occurred independently of wellbore measurement. Similarly reamer cutter block positions were recorded to be compared with wellbore measurements. In this way data from the wellbore measurements can be processed and compared with calibration, block positions, vibration, etc., or as required by the drilling application, to provide a comprehensive set of wellbore measurements and verify underreaming.

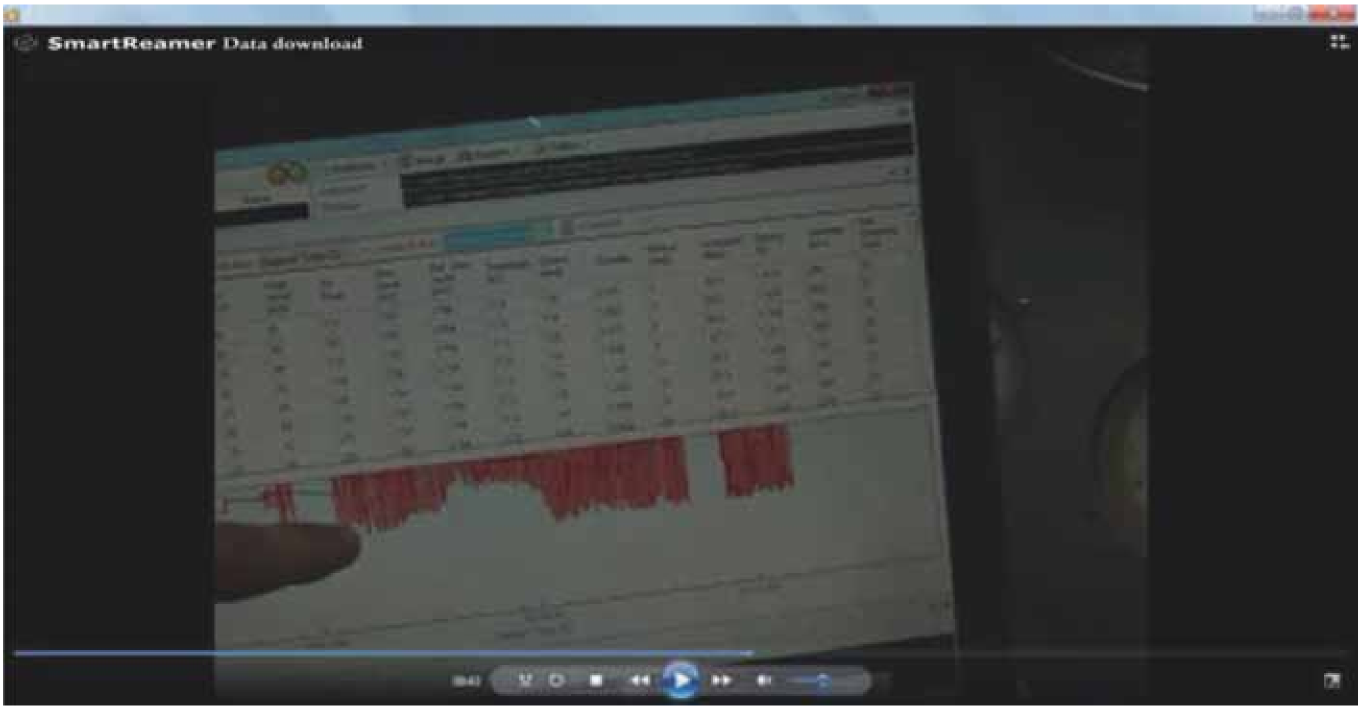


Figure 3. A screen-shot of Smart Reamer Calliper raw data with under-reamed hole size immediately verified on the rig-floor.

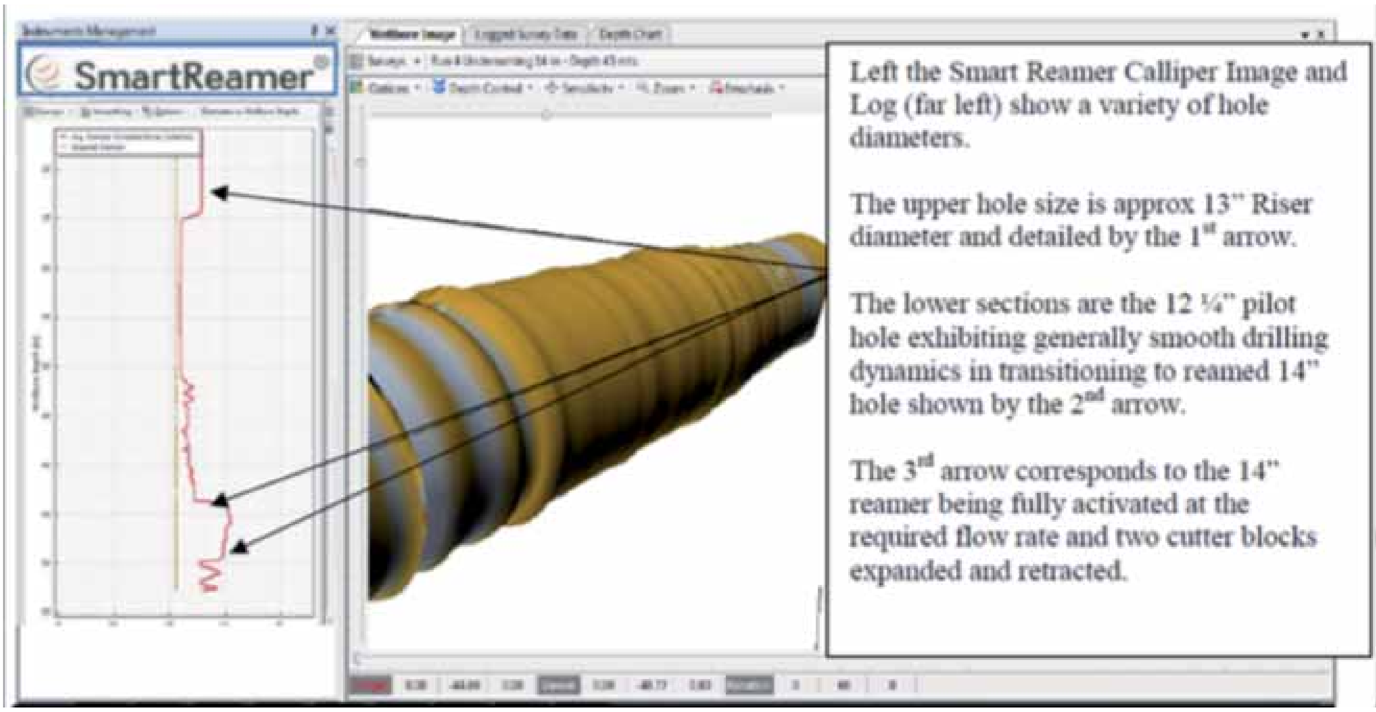


Figure 4. Screen-shot from Smart Reamer software shows a 3D hole shape/plot from reaming test run.

Smart Reamer Calliper Data

The Smart Reamer Calliper data was successfully recorded in tool memory and downloaded at the rig-floor after each run in the riser, casing, and open hole, prior to under-reaming and the under-reamed hole. These runs were witnessed by one of the project sponsor representatives. A wireline multi-arm calliper tool was then run to check the open hole under-reamed size from 12 ¼" - 14". Subsequently, the Smart Calliper data was depth matched (additional measurements include vibration, azimuth, inclination, temperature, pressure, RPM, WOB, torque) to form logs of wellbore diameters and wellbore profiles of Well C1 with the comparison of wireline calliper data (Fig. 2).

This comparison shows reasonably good matches with wireline calliper data. At 38m there was a noticeable

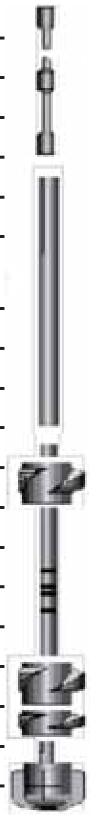
BHA	Component	Length (m)	Gauge/OD
	5" Drill Pipe	228.51	5
	6*5" HWDP	227.51	5
	Catcher Sub Churchill	170.72	8.25
	Jar with XO	167.75	8.12
	7*5 HWDP	163.99	5
	XO	153.06	8
	5*8 1/4" Drill Collar and XO	86.78	8.25
	Smart Reamer Calliper	40.71	8.625
	Flex Collar	36.23	7.938
	Float	27.27	8
	Screen	26.66	8
	12 1/8 IB Stab	24.37	12.125
	MWD HOC	22.53	8.15
	HCIM	17.78	8
	DGR	15.03	8
	PWD	13.61	8
	12 1/8" Stab	11.21	12.125
	12 1/8" Stab		12.125
	Steerable Motor	8.90	9.625
	12 1/4" Tricone Bit	0.32	12.25

Table 4. BHA incorporated with MWD.

measurement discrepancy at the casing shoe. This was because the tool was not rotated across the shoe and the tool was programmed prior to running in hole to take measurements upon rotation. In the under-reamed hole the measurements showed good matches, except for some measured depth switches, due to wireline and drillpipe depth calculation differences.

It should be noted that third party wireline measurements were taken in an axial direction only with six point measurements within the wellbore, i.e., every 60°. In contrast, the Smart Calliper's functional versatility is illustrated by its surveying recording measurements, as per user input and can be 1500 per second.

Consequently, the Smart Calliper had 120 readings (or 20 times the resolution compared to the six wireline points per depth). Therefore, the Smart Calliper has much higher volumes of data that are available for later processing and detailed analysis by Smart Reamer Drilling Systems Ltd or by the oil company. The resolution per survey – (per 1° or fraction thereof) and according to the depth (per every 1 cm, 10 cm or 100 cm, etc.) of the Smart Calliper – can be user defined and increased or decreased to suit the drilling application.

Figure 3 shows a screen-shot data dump of the moment that the under-reaming was verified on the rig floor, with the raw data dump (Time of Flight) clearly showing the larger under-reamed hole (14") compared to the pilot hole (12 ¼").

Fig. 4 A Smart Reamer Calliper 3D hole shape plot was mapped with the 12 ¼" – 14" reamed hole, clearly visible on the left and a corresponding image on the right. Color coding shows the grey 12 ¼" undergauge hole to the brown 14" reamed hole.

The colored bands show activation and deactivation of the reamer corresponding to the cutter block position and calliper data, which is shown in both log and image data.

The reamer was purposely deactivated (seen twice on the left log), to compare cutter block positions and calliper wellbore diameter. This provides certainty of reamer, cutter and calliper measurements, especially where the indication/activation relies on the surface stand pipe pressure or drilling fluid flow.

Drilling Test at Well 4

The Smart Calliper tool was subject to another drilling test in the U.K., with the BHA shown in Table 4. A single run was made to the section's total depth of approximately 800m and measurements performed in slide and rotary mode with hole diameters, varying from 11", 12 ¼", 13" and 13 ½". Drilling consisted of a 12 ¼" Tricone bit and BHA 12 ⅛" stabilizers with a Flex collar and 6 ⅝" REG connections cross-over to the Smart Calliper tool. The drilling fluid was an environmentally friendly water-based mud. The formations were chalk, sand and Oxford clay, with inter-bedded shale and quartz, with typical soft to medium hardness on the scale and low uniaxial compressive strengths. Because the Smart Calliper tool was placed directly above the Flex Collar, the tool was subject to the highest bending moments and stress in the BHA. Despite this, the tool survived the 59 hours on bottom directional drilling without any failure.

Conclusion

It is pleasing to note the Smart Calliper tool has successfully passed the qualification tests. The characteristics of the tool system can be summarized as follows:

- The industry's first fit-for-purpose monitoring system for wellbore diameter measurements in real-time under-reaming (hole opening) operation.
- Fully unrestricted inner-diameter (ID) and flow path to allow drop-ball and retrievable BHA below.
- Can be used as a standalone (memory) system in the BHA or drillstring.
- Calibration system capable of measuring fluid properties such as density, sound speed when required.
- Built-in vibration sensors to allow drilling and under-reaming optimization.
- Built-in directional/inclination sensors to allow additional survey data collection if required.
- Robust tool that withstood the weight, vibration, torque and loading associated with the larger 12 ¼" BHA components above and below.
- The tool's electronics communication performed satisfactorily with a standard MWD pulser and allowed real-time MWD data transfer to a surface decoder.
- Patents granted in international jurisdictions for various drilling and underreaming applications.

Acknowledgements

The authors wish to thank Saudi Aramco for their permission to publish this paper and also thank Saudi Aramco, Technology Strategy Board UK and Perenco UK for their financial and technical support.

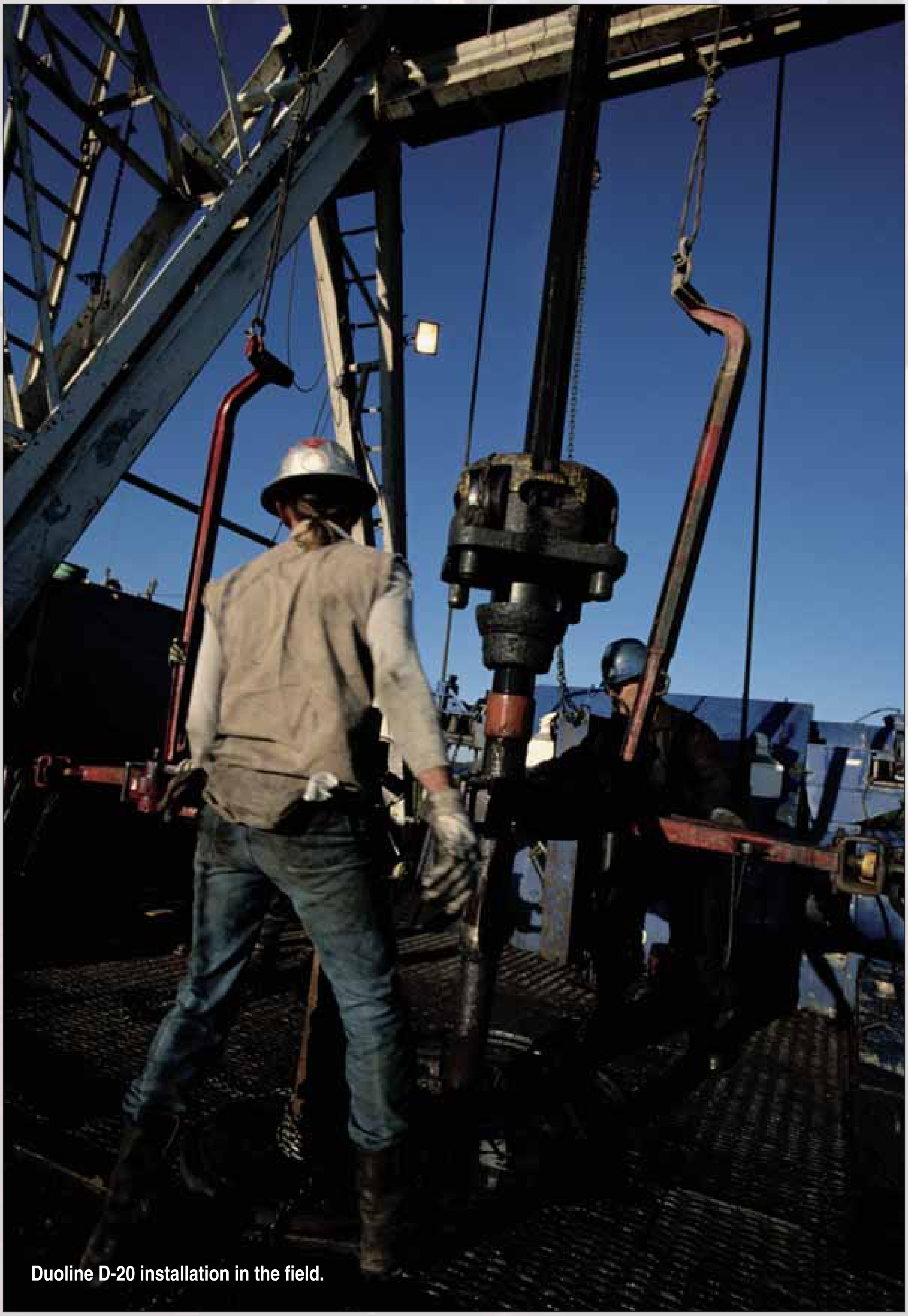
Biographies

Wajid Rasheed is CEO and Founder of Smart Reamer Drilling Systems Ltd. His work has focused on development of new drilling and completion technology including the underreaming segment since 1999. Prior to founding Smart Reamer in 2009, he worked for Andergauge and consulted for oilfield service companies and oil and gas operators. Rasheed has numerous patents granted in the US and Europe. He has published over 200 articles incl. 8 SPE papers.

Shaohua Zhou is a Senior Petroleum Engineering Consultant of the Drilling Technology Team, Upstream Advanced Research Center (EXPEC ARC) of Saudi Aramco. His work is primarily in drilling technology research and field implementation. Prior to joining Saudi Aramco in 2001, he worked for Baker Hughes as Geomechanics Coordinator for Europe and Africa, responsible for product development and oil field services for a number of oil and gas operators.

His education background includes B.S. and M.S. degrees in applied geophysics for petroleum exploration from Chengdu University of Technology, China and a Ph.D. degree in Geoscience from the University of Adelaide, Australia.

Protecting the Internal Surface Against Corrosion



Duoline D-20 installation in the field.

# of Oilfield Tubulars

By David Marshall, President, Duoline Technologies.

Corrosion in the oilfield can be caused by many sources: such as H_2S, HCl, CO_2, SO_2, brinish disposal water and highly acidic soil conditions, among others. Corrosion reduces productivity and causes downtime for maintenance, or worse, replacement. Each year, corrosion costs oil and gas operating companies billions of dollars in lost revenue and reduced operating profit.

Operating companies involved in oil and gas production have to abide by safe and timely production schedules. In many instances, fluids are so highly corrosive that most tubulars will experience a greatly diminished life cycle without some sort of protection.

There are ways to minimize the effects of corrosion on the internal surface of oilfield tubulars. The two most commonly used forms of protection are coatings and liners. However, before making any specification for an application it is necessary to have some basic knowledge of both coatings and liners.

Internal Plastic Coatings (IPC)

Originally, most internal coatings were organic solvent based. However, in the 1970s, pressured by the Clean Air Act, the industry implemented powder coatings to cut the use of solvents, hence reducing emissions. Efforts to coat with powder are often unsuccessful because the adhesion of coating to the pipe is ineffective.

One reason for this is that these coatings are thin and unable to resist impact, thus leading to aggressive localized corrosion. In addition, the coatings are neither of universal thickness, nor are they found throughout the entire product. Over time, these imperfections grow, ultimately resulting in a complete failure of the piping and shut down of the system.

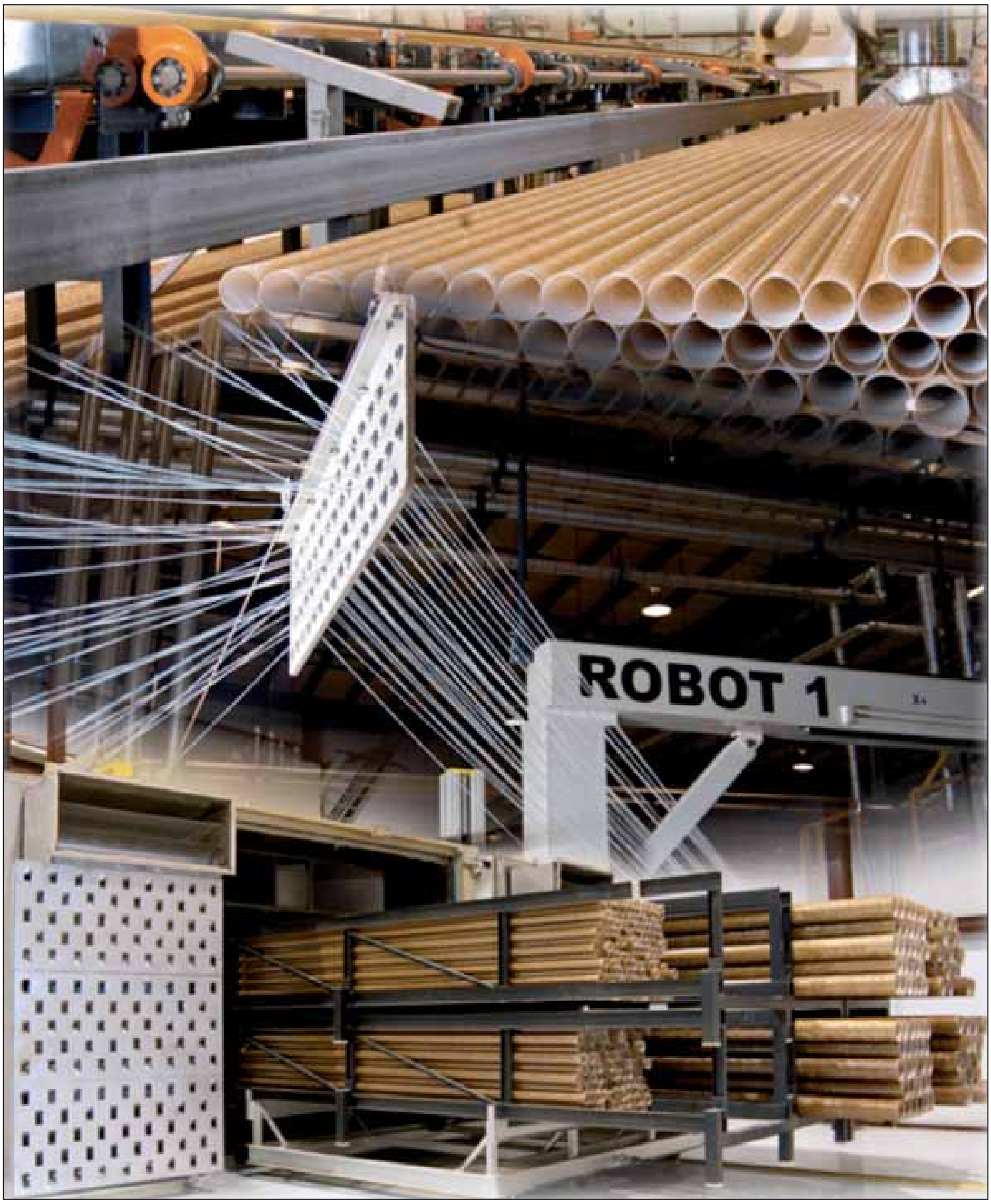
While many of the powder coatings have improved, it is essential to understand what kind of parameters are necessary to ensure success. For a comparison between Internal Plastics Coatings (IPC) and Glass Reinforced Epoxy (GRE) Liners see Fig. 1.

Before choosing powder coating options, it is important that qualification tests are conducted, many coating standards having originated from the external coating business. Confusion over proper procedures can arise from the extensive number of ANSI, AWWA, API, NACE, DIN and ASTM standards associated with coatings and paint; these may not be suitable for internal coatings. Care has to be taken that these standards are not confused with one another and that the testing during fit for purpose trials is relevant to the system in question.

Internal Tubular Polymer Liners

In order to properly select a liner, it is essential accurately to assess the entire environment to which

Duoline D-20 liner being installed in an oilfield tubular for a project in Eygpt to protect the pipe from corrosion under the supervision of Licensee MaxTube.



Duoline Technologies plant in Gilmer, TX produces a high quality Glass Reinforced Epoxy(GRE) liner to protect oilfield tubulars from corrosion.

the liner will be exposed during well servicing and treating operations before making a decision. Without a complete evaluation of the well, environment specifiers could actually reduce the allowable operating temperature and pressure for a liner.

Thermoset glass reinforced epoxy (GRE) liners and polyvinyl chloride (PVC) liners for lower temperature applications are the most common options. Recent developments include a family of liners that vary in chemical resistance but share a primary distinguishing feature – the allowable service temperature of each liner material.

A comparison between GRE and other liners is shown in Fig. 2.

Overall, glass reinforced epoxy (GRE) liners have solved the problem faced by other tubular corrosion control options. GRE lining systems have a proven track record in a great number of demanding environments, including water injection, CO_2

Fig 1.

Internal Plastics Coatings (IPC)	GRE Liners
IPC susceptible to damage from wireline tools and coil tubing operations	Durable 50-95 mil thickness is highly resistant to wireline damage and coiled tubing intervention
IPC can flake off upon penetration by trapped gas molecules	High hoop strength modulus and system has very low permeability
IPC specific per application environment	GRE systems are adaptable to a large range of environment and able to accommodate a changing injection profile

Fig 2.

Other Poly Liners	Glass Reinforced Liners
Liners lacking reinforcement fibers are susceptible to collapse under rapid depressurization	GRE liners have high hoop strength, are resistant to collapse under rapid depressurization
Most limited to 160°F	Suitable for costly applications up to 285°F
Typically suited to low end service conditions	Used in installations for 'standard' API or higher service 'Premium Gas Tight' connections
Can require factory rework	Easily reusable
Can require coupling protection	Requires only standard couplings
Limited Connections	Available in a wide range of premium and API connections

injection, gas production, gas-lifted oil production and chemical disposal wells, both onshore and offshore. They have an outstanding performance history in harsh environments containing CO_2 and H_2S. GRE liners have successfully prevented corrosion in gas production wells with high temperatures.

According to the company, one GRE liner that has proved successful in the field is fabricated exclusively by Duoline ® Technologies. The liner, manufactured with a filament winding and high temperature cure process, is the only fiberglass-epoxy lining system in the marketplace today, with over 33 years of accumulated field history.

The liner has proved to be the most abrasion-resistant coating or lining product in downhole wireline trials in deviated wells. It is acid compatible, resistant to impact, resistant to gas service failures common to other coatings or linings, premium connection compatible, chemically resistant and tolerant to common tension and bending loads. Figures 3 and 4 show two examples of the successful installation of the liners.

They were installed in an Offshore Gas Injector well in Liverpool Bay in 1998 with a well depth of 5,700 feet, an injection rate of H_2S and CO_2 present at 53°C (see Fig.3).

The liners were also used in a Gas Producer well in the Dagang field in China in 2001 in an operational temperature of 165°C with CO_2 present (see Fig. 4).

Company and Field Location Details:

SECTION	1.1	COMPANY	**BHP**
LOCATION	United Kingdom	REGION	Europe/North Sea
FIELD	Liverpool Bay	NO. OF WELLS	1

Fig 3.

Well Details:

TYPE OF WELL	**Offshore Gas Injector**	WELL DEPTH	5,700ft
TUBULAR SIZE/DETAILS	7", 29ppf, L-80	CONNECTION	Hunting Interlock Seallock-FGL
MAXTUBE PRODUCT	**DUOLINE 20**	OPERATING TEMP.	129oF (53oC)
H_2S PRESENT	5% (50,000 ppm)	CO_2 PRESENT	2%
FLUID INJECTED	n/a		
ORIGINAL INSTALLATION DATE	1998		
COMMENTS	Injection rate 35 MMscfd		

Print Full Details For Case History Shown

Company and Field Location Details:

SECTION	4.1	COMPANY	**Dagang Oilfield**
LOCATION	China	REGION	Asia Pacific
FIELD	Dagang	NO. OF WELLS	Several

Fig 4.

Well Details:

TYPE OF WELL	**Gas Producer**	WELL DEPTH	4,000 - 4,500 metres
TUBULAR SIZE/DETAILS	2.7/8' and 3.1/2', L-80	CONNECTION	8rd EUE
MAXTUBE PRODUCT	**DUOLINE 20/30**	OPERATING TEMP.	329oF (165oC)
H_2S PRESENT	0.018% (180 ppm)	CO_2 PRESENT	0%
FLUID INJECTED	n/a		
ORIGINAL INSTALLATION DATE	2001		
COMMENTS	9% Mol of CO2 Present Duoline 20 & Duoline 30 used (mixed string)		

Print Full Details For Case History Shown

D- 20 lined tubing quick laying speed with rudimentary equipment for the project in Egypt under the guidance of Licensee MaxTube.

Conclusion

In order for oil and gas companies to lower overall tubular capital expenditure costs and to reduce tubular maintenance and corrosion prevention, they must begin with a solid knowledge of the best options available to them. The most effective way to minimize the cost of corrosion on the internal surface of oilfield tubulars starts with a solid knowledge of coatings and liners.

One of the key factors influencing the decision making process will be the environment in which the tubulars will be operating. In some environments coatings are more appropriate for protection, while for others liners are the better choice. However, even among liners there are key differences. For over 30 years GREs have been proven to outperform other polymers in protecting tubulars from corrosion and abrasion.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2011–2012: 704
2013–2014: 188
and counting
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Opening Ceremony

Monday, 21 April 2014, 18:00 – 22:00

AlSeef Hall, Khobar

ATS&E 2014

Jeff Spath
President
Society of Petoleum Engineers

AbdulRahman AlWuhaib
Senior Vice President, Downstream
Saudi Aramco

Ashok Belani
Executive Vice President, Technology
at Schlumberger

Khalid Nouh
President APME Region
Baker Hughes

The Opening Ceremony of the 2014 Annual Technical Symposium & Exhibition (ATS&E) will include remarks by AbdulRahman AlWuhaib, Senior Vice President of downstream at Saudi Aramco, Jeff Spath, SPE President, Khalid Nouh, President of Middle East & Asia Pacific Region at Baker Hughes and Ashok Belani, Executive Vice President of Technology at Schlumberger. The opening ceremony will be attended by senior management from major regional and international energy companies, representatives from government ministries and departments, and engineering and technical industry professionals.

Panel

Wednesday, 23 April

"How to Unlock the Full Potential

Panelists

Ali H. Dogru
Fellow
Saudi Aramco

Judson L. Jacobs
Senior Director
IHS Cambridge Energy
Research Associates

Pieter Kapteijn
Technical Director
Maersk Oil

Technical Sessions

22-24 April 2014, 08:00 – 15:20 PM

Alseef Hall, Khobar

The ATS&E program features a rich technical program with more than 20 sessions, consisting of more than 90 papers. Moreover, knowledge sharing E-Posters are located in the exhibition where they will provide a very unique experience due the availability of animation, audio and visual experience. SPE-SAS is proud of its highly technical sessions as they are considered to be of the finest and selectively picked in the region.

UNATTAINABLE
UNSUSTAINABLE
UNCONVENTIONAL
MADE POSSIBLE

Discussion

2014, 12:45 – 15:00

of Upstream Technology"

Moderator

Nicholas W. Gee
Executive Vice President
Strategy & Development
Weatherford

Tim Probert
President
Strategy & Corporate Development
Halliburton

Samer S. AlAshgar
Manager
Saudi Aramco

Luncheon Keynote Speakers

22-24 April 2014, 11:30 – 12:45 PM

Luncheons will be provided daily at the venue for all registered delegates and will be served at the main hall next to the stage, which will instigate an outstanding networking environment. First day luncheon will be provided by Schlumberger and will be initiated after a welcoming speech by Vincent Tourillon, HSE Vice President in Middle Eastern Area at Schlumberger. Halliburton have generously hosted the second day's luncheon. During this luncheon, host video will be displayed as a looping background. Final day's luncheon is hosted by Baker Hughes. This luncheon will commence after welcoming message delivery by Mario Ruscev, Chief Technology Officer at Baker Hughes.

Mario Ruscev
Chief Technology Officer
(April 24, 2014) –
Baker Hughes Luncheon

Video Broadcast
Halliburton
23 April

Vincent Tourillon
VP HSE MEA
(April 22, 2014) –
Schlumberger's Luncheon

Sessions

Schedule

		Hall A	Hall B
Tuesday, 22 April 2014	0800-0930 hours	Petrophysics & Formation Evaluation (1)	Production Operations and Technologies (1)
	1000-1130 hours	Stimulation & Completion Optimization (1)	Drilling & Workover Operations (1)
	1245-1415 hours	Reservoir Engineering & Management (1)	Reservoir Characterization & Geophysics
	1420-1520 hours	Improved Oil Recovery & Enhanced Oil Recovery (IOR & EOR) (1)	Drilling & Workover Operations (2)
Wednesday, 23 April 2014	0800-0930 hours	Reservoir Modelling & Simulation	Petrophysics & Formation Evaluation (2)
	1000-1130 hours	Stimulation & Completion Optimization (2)	Improved Oil Recovery & Enhanced Oil Recovery (IOR & EOR) (2)
	1245-1500 hours	**Panel Discussion** ***"How to Unlock the Full Potential of Upstream Technology"***	
Thursday, 24 April 2014	0800-0930 hours	Production Operations and Technologies (2)	Improved Oil Recovery & Enhanced Oil Recovery (IOR & EOR) (3)
	1000-1130 hours	Production Facilities Technologies	Unconventional Resources
	1245-1415 hours	Drilling & Workover Operations (3)	Reservoir Engineering & Management (2)
	1420-1520 hours	Production Operations and Technologies (3)	Stimulation & Completion Optimization (3)

KEY

- E&P & Geoscience
- Reservoir
- Engineering Projects & Facilities
- Petrophysics
- Drilling & completions
- Unconventional
- Production & Operation

Program

Session 1 **Tuesday, April 22** **Hall-A**

Petrophysics And Formation Evaluation (1) 08:00-09:30

Session Chairpersons: Richard Palmer, Saudi Aramco
William Bryant, Baker Hughes

8:00 – 8:10	Keynote Speaker	Khalid Al-Subai (Manager Reservoir Description & Simulation, Saudi Aramco)
8:10 – 8:30	SPE-SAS-312	Using New Spectroscopy Tool to Quantify Elemental Concentrations and TOC in an Unconventional Shale Gas Reservoir: Case Studies from Saudi Arabia *Ahmed Al-Salim, Yacine Meridji, Nedhal Musharfi, Hilal Al-Waheed;, Saudi Aramco; Pablo Saldungaray, Susan Herron, Marina Polyakov;, Schlumbergero*
8:30 – 8.50	SPE-SAS-312	Integrated Formation Evaluation of Tight-Gas Delineation Wells: Best Practices and Lessons Learned *Nasreddine Hammou, Ali Balawi, Saudi Aramco; Mahmoud Eid, John Quirein, Halliburton*
8:50 – 9:10	SPE-SAS-317	Effective Geo-steering Using High Resolution Electrical Image and Deep Azimuthal Resistivity *Asim Mumtaz, Mahmoud Hameed, Craig Saint, Baker Hughes; Rohit Kumar, Saud Faihan Otaibi, Khafji Joint Operations*
9:10 – 9:30	SPE-SAS-318	A New Model to Determine Wettability from Multi-frequency Dielectric Dispersion Measurements *Khaled H. Sassi, Schlumberger; Ahmad Kadoura, King Abdullah University of Science and Technology*

Session 2 Tuesday, April 22 Hall-B

Production Operations and Technologies (1) 08:00-09:30

Session Chairpersons: Nashi Otaibi, Saudi Aramco
Andrew Boucher, Shchlumberger

8:00 – 8:20	SPE-SAS-334	A Graphical Method to Evaluate Multi-zone Completion *Assad Barri, Sami Alnuaim, King Fahd University of Petroleum & Minerals .*
8:20 – 8:40	SPE-SAS-385	A Saudi Arabia Giant Oil Field Development: Lessons from Integrating Technologies *James Arukhe, Shadi Hanbzazah, Abdulrahman Ahmari, Laurie Duthie, Karam Yateem, Saudi Aramco*
8:40 – 9:00	SPE-SAS-341	Fluid Production Studies Using NMR and High-Frequency Dielectric Permittivity *Reza Taherian, Andrea Valori, Ahmad AlZoukani, Farhan Ali, Shlumberger Dhahran Carbonate Research Center*
9:00 – 9:20	SPE-SAS-343	Design and Development of Non-aqueous Suspension for Suspending Varied Sized Solid Particulates of a Conventional Diverter *Snehalata Agashe, Prajakta Patil, Neelam Raysoni, and Nisha Pandya, Halliburton*

Session 3 Tuesday, April 22 Hall-A

Stimulation and Completion Optimization (1) 10.00-11.30

Session Chairpersons: Eduardo Soriano, Halliburton
Moataz Harbi, Saudi Aramco

10:00 – 10:10	Keynote Speaker	Hamad Al-Mari (General Supervisor Remote Field Gas Production Engineering, Saudi Aramco)
10:10 – 10:30	SPE-SAS-357	Optimizing Acid Stimulation Treatment Design in South Ghawar Power Water Injectors *Mortada Alkadem, Hasan Tammar, Ahmed Jundal, Abdulaziz Mulhem, Saudi Aramco*
10:30 – 10:50	SPE-SAS-361	Use of Emulsified Acid System with Corrosion Protection up to 350°F *Sushant Wadekar, Nisha Pandya, Halliburton.*
10:50 – 11:10	SPE-SAS-363	Application of MFO Injections Procedure for MSF Packers Integrity Diagnostic *Ikhsan Nugraha, Rifat Said, Saudi Aramco*
11:10 – 11:30	SPE-SAS-365	A Novel Non-damaging Approach toIsolate Open-hole Lateral that Allowed Performing Mechanical Descaling in the Non-monbore Cased Completion: A Case Atudy in Saudi Arabian Carbonate Reservoir *A.E. Mukhliss, T.M.Ogundare, A.A.Dashash, A.R.Malik, Saudi Aramco, E.V. Rivadeneira, N. Molero, Schlumberger*
E-poster Alternate	*SPE-SAS-388	How Malfunctioning Completion Accessories Affected Well Performance Offshore Saudi Arabia *Mustafa Bawazir, Schlumberger, Ahmed Bubshait, Mohammed Al-Khanferi, Saudi Aramco; Mahmoud Abd El-Fattah, Hussain Al-Shabibi, Schlumberger*

Session 4 Tuesday, April 22 Hall-B

Drilling and Workover Operations (1) 10.00-11.30

Session Chairpersons: Opeyemi Adewuya, Saudi Aramco
Ahmed Taher, Halliburton

10:00 – 10:10	Keynote Speaker	Faisal Al-Nughaimesh (Manager Offshore & Gas Drilling Engineering, Saudi Aramco)
10:10 – 10:30	SPE-SAS-305	Real Time Kick Detection Applying an Ultrasonic Caliper Featuring a Downhole Sonic Speed Measurement for Calibration Purposes *Behzad Elahifar, Franz Fasch, Advanced Drilling Solutions, Gerhard Thonhauser, University of Leoben, Christian Tollschein, TDE Thonhauser Data Engineering*
10:30 – 10:50	SPE-SAS-308	First Installation of 16-in. Solid Expandable Liner Solves Shallow Drilling Problems; Opens New Doors for Hole Size Preservation *Yasser Atallah, Enventure Global Technology; Ali Shaikh, Roberto Duran, Khaled Khater Abouelnaaj, Saudi Aramco; Jerry Fritsch, Stacey Andrews, Roy Baker, Enventure Global Technology*
10:50 – 11:10	SPE-SAS-310	Exploration Drilling Performance Optimization in Red Sea Shallow Water: Shifting West with Offshore Exploration Drilling Best Practices *Saleh Khalifa, Suliman M. Azzouni, Shrikant X. Tiwari, Opeyemi A. Adewuya, Saudi Aramco*

Session 5 Tuesday, April 22 Hall-A

Reservoir Engineering and Management (1) 12.45-14.15

Session Chairpersons: Abdulbari Arefi, King Saud University
Ahmed Bubshait, Saudi Aramco

12:45 – 13:05	SPE-SAS-346	Application of Best in Class Reservoir Management Practices in the Production Startup of a New Giant Field Development through Integration of Real Time Data: A Case Study *Faisal Al-Ghamdi, Majid Al-Otaibi, Abdel Abitrabi Ballan, Saudi Aramco*
13:05 – 13:25	SPE-SAS-349	Isothermal Oil Compressibility Curve Crossing *Muhammad Al-Marhoun, Reservoir Technologies*
13:25 – 13:45	SPE-SAS-351	Comprehensive Reservoir Monitoring Program: Challenges, Design, Implementation, and Added Value in a Large Carbonate Reservoir *Ali Al-Julaih, Naseem Al-Dawood, Saudi Aramco*
13:45-14:05	SPE-SAS-352	Sweet Spot Identification and Optimum Well Planning: an Integrated Workflow Applied in a Sector of Giant Carbonate Mature Oil Reservoir in Saudi Arabia *Abdullah Alsadah, Ahmed Al-Huthali, Mohamed Bouaouaja, Abdullah AlSafi, Saudi Aramco*
E-poster Alternate	*SPE-SAS-380	Development of Mature Fields Using Reservoir Opportunity Index: A Case Study from a Saudi Field *Alfonso Varela, Ahmad Al-Hutheli, Saad Al-Mutairi, Saudi Aramco*

UNATTAINABLE UNSUSTAINABLE UNCONVENTIONAL MADE POSSIBLE

Session 6 Tuesday, April 22 Hall-B

Reservoir Characterization & Geophysics 12.45-14.15

Session Chairpersons: Khalid Hawas, Saudi Aramco
Marwan Thagafy, Saudi Aramco

12:45-12:55	Keynote Speaker	Aus Al-Tawil (Manager Reservoir Characterization, Saudi Aramco)
12:55 – 13:15	SPE-SAS-344	Anisotropy effect in geosteering: Anisotropy and D2B estimate from directional resistivity tool *Teruhiko Hagiwara, Pedro Anguiano-Rojas, Aramco Services Company*
13:15 – 13:35	SPE-SAS-345	Dynamic Reservoir Characterization with PTA: Clastic Environments *Rodolfo Phillips Guerrero, Saud Binakresh, Saudi Aramco*
13:35 – 13:55	SPE-SAS-375	Narrowing Formation Fracture Gradient Uncertainty by Integrating Geomechanics and Micro-Fracturing Test Results: A Case Study from Saudi Arabia *Zaid Alrayyes, Salem Alsuwadi, Joe Ansah, and Bader Almutairi, Saudi Aramco; Satya Perumalla, Katharine Burgdorff, and Saad Imtiaz, Baker Hughes*
13:55-14:15	SPE-SAS-384	Evaluation of Diagenetic Scaling on Flow-back Proppants *Jajati Nanda, Omprakash Pal, Halliburton*

Session 7 Tuesday, April 22 Hall-A

Improved Oil Recovery & Enhanced Oil Recovery (1) 14.20-15.20

Session Chairpersons: Saleh Mutairi, Chevron
Ali Alyousif, Saudi Aramco

14:20 – 14:40	SPE-SAS-320	High Performance EOR System in Carbonate Reservoirs *Khaled Abdelgawad, Mohamed, King Fahd University of Petroleum & Minerals*
14:40 – 15:00	SPE-SAS-324	State-of-the-Art of In-Depth Fluid Diversion Technology: Enhancing Reservoir Oil Recovery by Gel Treatments *Ming Han, Amar J. Alshehri, Dimitrios Krinis, Stig Lyngra, Saudi Aramco*
15:00 – 15:20	SPE-SAS-325	Investigation of Optimum Salinity of Injected Water in Carbonate Reservoirs using Wettability Measurement and Core Flooding *Murtadha Alshaikh, Mohammad Sharifi, Saudi Aramco*

Session 8 Tuesday, April 22 Hall-B

Drilling and Workover Operations (2) 14.20-15.20

Session Chairpersons: Mahdi Jezani, Saudi Aramc
Jaywant Kumar Verma, Schulmberger

14:20 – 14:40	SPE-SAS-302	Hybrid Drill Bit Technology: A New Approach to Drilling Challenging Large Hole Size Sections Saves Up To 3 Days *Jake Drew, Baker Hughes*
14:40 – 15:00	SPE-SAS-306	Optimizing Saudi Aramco Reentry Drilling Operations with the First Worldwide Combined High Dogleg RSS & Underreaming Drilling System *Rami Saleh, Noor Chozin Ali, Yousif Abuahmad, Naser Otaibi, Saudi Aramco; Ahmed Osman, Mazhar Farid, Anis Ali, Islam El-Fouly, Schlumberger*
15:00 – 15:20	SPE-SAS-309	Statistical Approach to Forecasting Fluid Loss Solutions *Alexey Alexeyenko, Saudi Aramco.*
E-poster Alternate	*SPE-SAS-394	Nanotechnology Applications for Minimizing Geo-Mechanical-Related Challenges While Drilling Intercalated Sediments *Wael El Sherbeny, Hesham Al-Baddaly, Ayman Rahal, Mohamed Said, Baker Hughes, Douglas Hardman and Todd Henry Apache Corporation*

Session 9 — Wednesday, April 23 — Hall-A

Reservoir Modeling & Simulation 08.00-09.30

Session Chairpersons: Olugbenga Olukoko, Saudi Aramco
Saud Hoti, Saudi Aramco

8:00 – 8:10	Keynote Speaker	Ali Al-Muallem (General Supervisor Reservoir Simulation, Saudi Aramco)
8:10 – 8.30	SPESAS-354	Enhanced Reservoir History Matching for Large Scale Reservoirs via Incorporating Satellite-based InSAR Data *Klemens Katterbaue, Ibrahim Hoteit, Shuyu Sun, King Abdullah University of Science & Technology*
8:30 – 8:50	SPESAS-356	Smart Completion Design for Managing Steam Injection in CSS Process *Suranto AM, Wisup Bae, Sejong University*
8:50 – 9:10	SPE-SAS-381	Density-Driven Flow Simulation in Anisotropic Porous Media: Application to CO2 Geological Sequestration *Ardiansyah Negara, Amgad Salama, Shuyu Sun, King Abdullah University of Science and Technology*
9:10 – 9:30	SPE-SAS-382	Integrating I-Field Data into Simulation Model History Matching Process *Bevan Yuen, Olugbenga Olukoko, Joseph Ansah, Saudi Aramco*

Session 10 | Wednesday, April 23 | Hall-B

Petrophysics And Formation Evaluation (2) 08:00-09:30

Session Chairpersons: Charles Bradford, Saudi Aramco
Pablo Saldungaray, Schlumberger

8:00 – 8:20	SPE-SAS-313	Investigating Formation Water Salinity Using a Unique Water Extraction Technique in a Hydraulically Active Area *David Forsyth, M Witjaksono, Hussain Najrani, A. Silva, R Palmer, Saudi Aramco; Phil Mitchell, DAR ETS*
8:20 – 8:40	SPE-SAS-315	Shale Gas Characterization and Property Determination by Digital Rock Physics *Anas Almarzooq, Tareq Ghamdi; Saudi Aramco; Joel Walls, Safouh Koronfol, Moustafa Dernaika, Ingrain.*
8:40 – 9:00	SPE-SAS-316	Can Sourceless Density LWD Replace Wireline in Exploration Wells? Case Study from Saudi Arabia *Abdullah Alakeely, Yacine Meridji, Saudi Aramco*
9:00 – 9:20	SPE-SAS-319	Case Study: Application of Azimuthal Resistivity, Azimuthal Density and Resistivity Inversion to Geosteer in a Clastic Sand Stone Reservoir Stringer, Khafji Field, Saudi Arabia *Craig Saint, Asim Mumtaz, El-Said Noaman, Debasis Panda, Baker Hughes; Nasser Ali AI-Khaldi,Yousel AI-Dahferi,Sashi Sinha, Athbi Al-Sultan, KJO*
E-poster Alternate	*SPE-SAS-385	Characterization of Heavy Oil Properties in a Complex Shallow Miocene Reservoir in Saudi Arabia using NMR and other Advanced Log Measurements *Umar Idris, Gabor Hursan, Pablo Saldungaray, Hisham Azam, Saudi Aramco*

Session 11 Wednesday, April 23 Hall-A

Stimulation and Completion Optimization (2) 10.00-11.30

Session Chairpersons: Faisal Beheiri, Saudi Aramco
Saud Alquwizani, Saudi Aramco

10:10 – 10:20	SPE-SAS-358	Successful Field Application of Aqueous-Based Formation Consolidation Treatment Implemented in Nile Delta, Egypt *Sumit Songire, Amro Hassa, Mohamed Amer, Halliburton; Saber Farid, Jean-Marie Luijkx, Mohamed AbdelKhaleq, WASTANI*
10:20 – 10:40	SPE-SAS-364	Performance Evaluation and Challenges Using Openhole Multi-Stage Fracturing Completion to Develop Tight Gas Reservoirs in Saudi Arabia. *Mahdi Aldawood, Azly Abdul aziz, Ahmed M Al-Omair, Zillur Rahim, Saudi Aramco*
10:40 – 11:00	SPE-SAS-372	The First Successful Multistage Acid Frac of an Oil Producer in Saudi Arabia *Majid Rafie, Rifat Said, Muhammad Al-Hajri, Tariq Almubarak, Adel Al-Thiyabi, Ikhsan Nugraha, Saudi Aramco; Eduardo Soriano, Jared Lucado, Halliburton*
11:00 – 11:20	*SPE-SAS-378	Investigation of Core Length and CO_2 Phase Effects on the Propagation of Wormholes in Carbonate Rocks *Abdullah Sultan, Mohamed Mahmoud, KFUPM; Sarmad Khan, Steve Dyer, Xiangdong Qiu, Schlumberger*

Session 12 **Wednesday, April 23** **Hall-A**

Improved Oil Recovery & Enhanced Oil Recovery (2) 10.00-11.30

Session Chairpersons: Dr. Hazim Dmour, King Saud University
Mohammed Bataweel, Saudi Aramco

10:00 – 10:10	Keynote Speaker	Keynote Speaker: Mohammed Badri (Schlumberger Research Center)
10:10 – 10:30	SPE-SAS-321	A New Chemical EOR for Sandstone and Carbonate Reservoirs *Mohamed Mahmoud, K.A. Abdelgawad, M.M. Gadalla, King Fahd University of Petroleum & Minerals*
10:30 – 10:50	SPE-SAS-326	Extending the Applicability of Chemical EOR in High Temperature and High Salinity Carbonate Reservoir through Viscoelastic Materials *Madhar Sahib Azad, Abdullah Sultan , King Fahd University of Petroleum & Minerals*
10:50 – 11:10	SPE-SAS-328	Evaluation and Investigation of Miscible Flood in Kuwait – Case Study *Abdullah Alajmi, and Meshal Algharaib, Kuwait University, Ridha Gharbi, Huda Alenezi, Bader AlMatar, and Khalaf Al-Enezi, Kuwait Oil Company*
11:10 – 11:30	SPE-SAS-329	Monitoring Residual Surfactant in the Flowback and Produced Water – a Way Forward to Improve Well Productivity *Jayant P. Rane and Liang Xu, Multi-Chem A Halliburton Service*

Session 13 **Thursday, April 24** **Hall-A**

Production Operations and Technologies (2) 08:00-09:30

Session Chairpersons: Mohammed Khamis, Saudi Aramco
Alejandro Chacon, Halliburton

8:00 – 8:10	Keynote Speaker	Abdullah AL-Sultan (Petroleum Department Head, KFUPM)
8:10 – 8:30	SPE-SAS-335	Innovative Hot Oiling Operation in a Low BHP Well Minimizing Formation Damage: A Case Study *Zishaan M.W. Haindade, SPE, A. M. Mamen, SPE, Oil India Limited*
8:30 – 8.50	SPE-SAS-338	Intelligent Distributed Acoustic Sensing for In-well Monitoring *J. Xiao, Saudi Aramco; M. Farhadiroushan, Silixa Ltd; A. Clarke, Silixa Ltd; R.A. Abdalmohsen, E. Alyan, Saudi Aramco; T.R. Parker, J. Shawash, H.C. Milne, Silixa Ltd*
8:50 – 9:10	SPE-SAS-374	Characterization of Crude oil of Upper Assam Field for Flow Assurance *Nilesh Kumar Jha, RGIPT; Mohammad Shahid Jamal, GAIL India Ltd.; Diwakar Singh, ONGC Ltd.; Dr. Uma Shanker Prasad, RGIPT*
9:10 – 9:30	SPE-SAS-342	Application of Neural Network to Predict Gas Well Performance during Two- Phase Flow in Gas Condensate Reservoirs *Mohammad Al-Dhamen, Saudi Aramco*
E-poster Alternate	*SPE-SAS-387	Mulltiphase Flow Measurement Modeling of an Oil-Water Flow Through an Orifice Plate *Mohamed Nabil Noui-Mehidi, Michael Black, Saudi Aramco*

Session 14 — Thursday, April 24 — Hall-B

Improved Oil Recovery & Enhanced Oil Recovery (3) 08.00-09.30

Session Chairpersons: Ming Han, Saudi Aramco
Sulltan Enzi, Saudi Aramco

8:00 – 8:20	SPE-SAS-322	CO_2 Minimum Miscible Pressure (MMP) Estimation using Multiple Linear Regression (MLR) Technique *Osamah Alomair, Maqsood Iqbal, Kuwait University*
8:20 – 8:40	SPE-SAS-323	Foamability and Foam Stability of Several Surfactants Solutions: The Role of Screening and Flooding *Azmi Belhaij, Osama Al-Mahdy, King Saud University, Abdulrahman AlQuraishi, King Abdulaziz City for Science and Technology*
8:40 – 9:00	SPE-SAS-327	FAWAG using CO_2 Philic Surfactants for CO_2 Mobility Control for Enhanced Oil Recovery Applications *Muhammad Sagir, Isa M Tan, Muhammad Mushtaq, Muhammad Rehan Hashmat, Universiti Teknolgi PETRONAS*
9:00 – 9:20	SPE-SAS-330	Water –- Chemical Treatment and Management *Adrian Wiggett, Mostafa Elharakany BAKER HUGHES; Mohmmed Hady, Saudi Aramco*
E-poster Alternate	*SPE-SAS-377	Simulation of Single Well Tracer Tests for Surfactant-Polymer Flooding *Abdulkareem Al-Sofi, Peter X Bu, Jim S Liu, Lajor Benedek, Ming Han, Saudi Aramco*

Session 15 Thursday, April 24 Hall-A

Production Facilities Technologies 10.10-11.30

Session Chairpersons: Charles Vanorsdale, Saudi Aramco
Ahmed Muhammadi, Saudi Aramco

10:10 – 10:10	Keynote Speaker	Jamal Al-Mufleh (General Supervisor Gas Facilities, Saudi Aramco)
10:10 – 10:30	SPE-SAS-331	Thermoelectric Generators for Well Head Production Facilities *Ahmed Abu-Abed, Global Thermoelectric; Saad Turaiki, Midad Holding*
10:30 – 10:50	SPE-SAS-332	Novel Methods To Boost Production From Saudi Arabian Low Pressure Gas Wells, Increase Overall Recovery and Avoid Well Intervention *Bandar Al-Malki, Syed M Peeran, Saudi Aramco*
10:50 – 11:10	SPE-SAS-333	Downhole Electrical Disconnect Tool Enables the Parting and Subsequent Connection of the Upper Completion containing an ESP from the Lower Intelligent Completio *Ronaldo Izetti, Hardy Pinto, and Fabio Rosas, Petrobras; Lorenzzo Minassa, Ravi Vayeda, Benjamin Deyo, Gireesh Bhat, Desiderio Rodrigues, Antonio Bonfim, Halliburton*
11:10 – 11:30	SPE-SAS-376	Successful Inorganic Scaling Prediction in Early Conceptual Design Phase: Offshore Gas Field Development Experience *Ardian Nengkoda, Peter Birkle, Bader Harbi, Jamal Mufleh, Mofeed Awwami, Yasser Duailej, Mohammed Khaldi, Xiaolong Cai, Michael Haas, Ibrahim Alharith, Saudi Aramco*
E-poster Alternate	*SPE-SAS-392	Unconventional Flare Gas Recovery Systems (FGRS) *Samusideen Salu, Mohamed Soliman, Nisar Ahmad K Ansari, Saudi Aramco*

Session 16 Thursday, April 24 Hall-B

Unconventional Resources 10.00-11.30

Session Chairpersons: Kirk Bartko, Saudi Aramco
Khalid Sasi, Schlumberger

10:00 – 10:10	Keynote Speaker	Fred Arasteh, (Global Technical Director Weatherford)
10:10 – 10:30	SPE-SAS-367	Completing a Deep Unconventional Well with Wellbore Limitations in Saudi Arabia: Case Study *Ali Alsaihati, Tony Harris, Nayef Mulhim, Saudi Aramco; Jaime Rabines, Rick Ortiz, Rick Middaugh, Halliburton*
10:30 – 10:50	SPE-SAS-368	Shale Gas Field: Exploration, Exploitation and Development Strategies Globally *Waleed Anwar Saleem, Shahzaib Baber, Muhammad Osama Jafri, NED University of Engieering & Technology*
10:50 – 11:10	SPE-SAS-369	Environmentally Acceptable Swell Packer Fluid for Unconventional Reservoirs with High-Temperature Applications *Nisha Pandya, Rajendra Kalgaonkar, Dave Alison, Halliburton*
11:10 – 11:30	SPE-SAS-396	Characterization of Next-Generation Heavy Oil of Tar Mats in Carbonate Reservoirs and Understanding Its Role in Reserve Estimation and Oil Recovery Economics *Abdullah Almansour, King Abdulaziz City for Science & Technology; W.H. Al-Bazzaz, G. Saraswathy, Kuwait Institute for Scientific Research; B. Bai, Missouri University of Science & Tech*
E-poster Alternate	*SPE-SAS-379	Integrated Model for Sustainable Development (IMSD): Impact of Technology Integration *Ahmed Hasan, University of New Mexico*

Session 17 Thursday, April 24 Hall-A

Drilling and Workover Operations (3) 12.45-14.15

Session Chairpersons: Suliman Azzouni, Saudi Aramco
Karim El-Banna, Baker Hughes

12:45 – 13:05	SPE-SAS-303	A Productive Technique To Do Drilling Analysis and Risk Assessment *Ziad Sidaoui, Mohammed A.Q. Siddiqui, King Fahd University of Petroleum & Minerals ;Jahad Al-Dawood, Baker Hughes INTEQ*
13:05 – 13:25	SPE-SAS-304	New Hybrid Drill Bit with Innovative Technology Improves Drilling Efficiency in Challenging Jordanian Drilling Project *Ahmed Ismail, Waleed Mostafa, Baker Hughes; Hesham Mohamed BP Jordon*
13:25 – 13:45	SPE-SAS-307	Efficient Openhole Logging Operations for Horizontal Wells Use the Openhole Tractors. Field Experiences from TATWEER Petroleum Company-Bahrain *Moustafa Eissa, Shlumberger; Bill Ofield, Michael Down, Lana Al-Hashimi, Amir Hermes, Nicolas Murphy, Enrico Annovi, TATWEER Petroleum Schlumberger*
13:45-14:05	SPE-SAS-311	Bottom-Hole Assembly Management System (BHAMS) *Bader Alotaibi, Contreras Otalvora, William B, Nefai, Mohammad S, Saudi Aramco*

Session 18 — Thursday, April 24 — Hall-B

Reservoir Engineering and Management (2) 12.45-14.15

Session Chairpersons: Fahad Fassam, Saudi Aramco
Thamer Shamekh, Saudi Aramco

12:45 – 13:05	SPE-SAS-347	Integrated Modeling for Better Reservoir Management: a Case Study from a Large Carbonate Middle East Reservoir *Bader Shammari, Satya Putra, Hasan Nooruddin, Isidore Bellaci, Ahmad Shammari, Sauid Aramco*
13:05 – 13:25	SPE-SAS-348	On the Joint Optimization of Well Placement and Controls: A Strategy to Include Well Type and Number of Wells *Abeeb Awotunde, King Fahd University of Petroleum & Minerals*
13:25 – 13:45	SPE-SAS-350	Transport of Temperature Nanosensors Through Fractured Tight Rock: an Experimental Study *Mohammed Alaskar, Saudi Aramco; Kewen Li, Roland Home, Stanford University*
13:45-14:05	SPE-SAS-373	A Streamlined Process to Track Field Operations through Management Operations Dashboard *Mohammed Buraik, Hamad Naim, Abdullah Alakeely, Saudi Aramco*
E-poster Alternate	*SPE-SAS-386	Tar Area Development in a Giant Carbonate Field in Saudi Arabia *Lajos Benedek, Razally Ali, Humam Al-Ghamdi and Ahmed H. Al-huthali, Saudi Aramco*

Session 19 Thursday, April 24 Hall-A

Production Operations and Technologies (3) 14:20-15:20

Session Chairpersons: Faisal Khelaiwi, Saudi Aramco
Salman Gamber, Saudi Aramco

14:20 – 14:40	SPE-SAS-336	Field Deployment of a Novel Inlet Device for Multiphase Separator - Steps From R&D to Industrial Application *Sulaiman A. Jutaily; Iran D. Charry Prada; Syed Z. Haider; Lanre Oshinowo, Regis D. Vilagines, Saudi Aramco*
14:40 – 15:00	SPE-SAS-339	Intelligent Field Infrastructure Embedded Cyber Security Protection And Availability *Soliman Almadi, Noor Sharif, Saudi Aramco*
15:00 – 15:20	SPE-SAS-340	Creation of I-Field Operational Excellence Committee Yield Excellent Performance of Production Data Acquisitions and Field Optimizations *Hisham Al-Shuwaikhat, Mazen H. Modhai, Saudi Aramco*

Session 20 Thursday, April 24 Hall-B

Stimulation and Completion Otpimization (3) 14:20-15:20

Session Chairpersons: Fahad Meshal, Saudi Aramco
Rifat Said, Saudi Aramco

14:20 – 14:40	SPE-SAS-359	Advanced Well Completion Designs to Meet Unique Reservoir Requirements *Suresh Jacob, Khalid M. Naimi, Saudi Aramco*
14:40 – 15:00	SPE-SAS-362	Evaluate Fracturing Fluid Performance for Hydraulic Stimulation in Pre-Khuff Sandstone Reservoirs of Ghawar Gas Field *Prasanta Das, Zillur Rahim, Saudi Aramco*
15:00 – 15:20	SPE-SAS-366	CT Extended Reach Acid Stimulation in Openhole Wells, Offshore Saudi Arabia: A 23-Well Case Study *James Arukhe, Shadi Hanbzazah, Abdulrahman Ahmari, and Rotimi Adesegha, Saudi Aramco; Joan Perez, Jose Noguera, Gopi Krishnan, and Amit Nakhwa, Halliburton*

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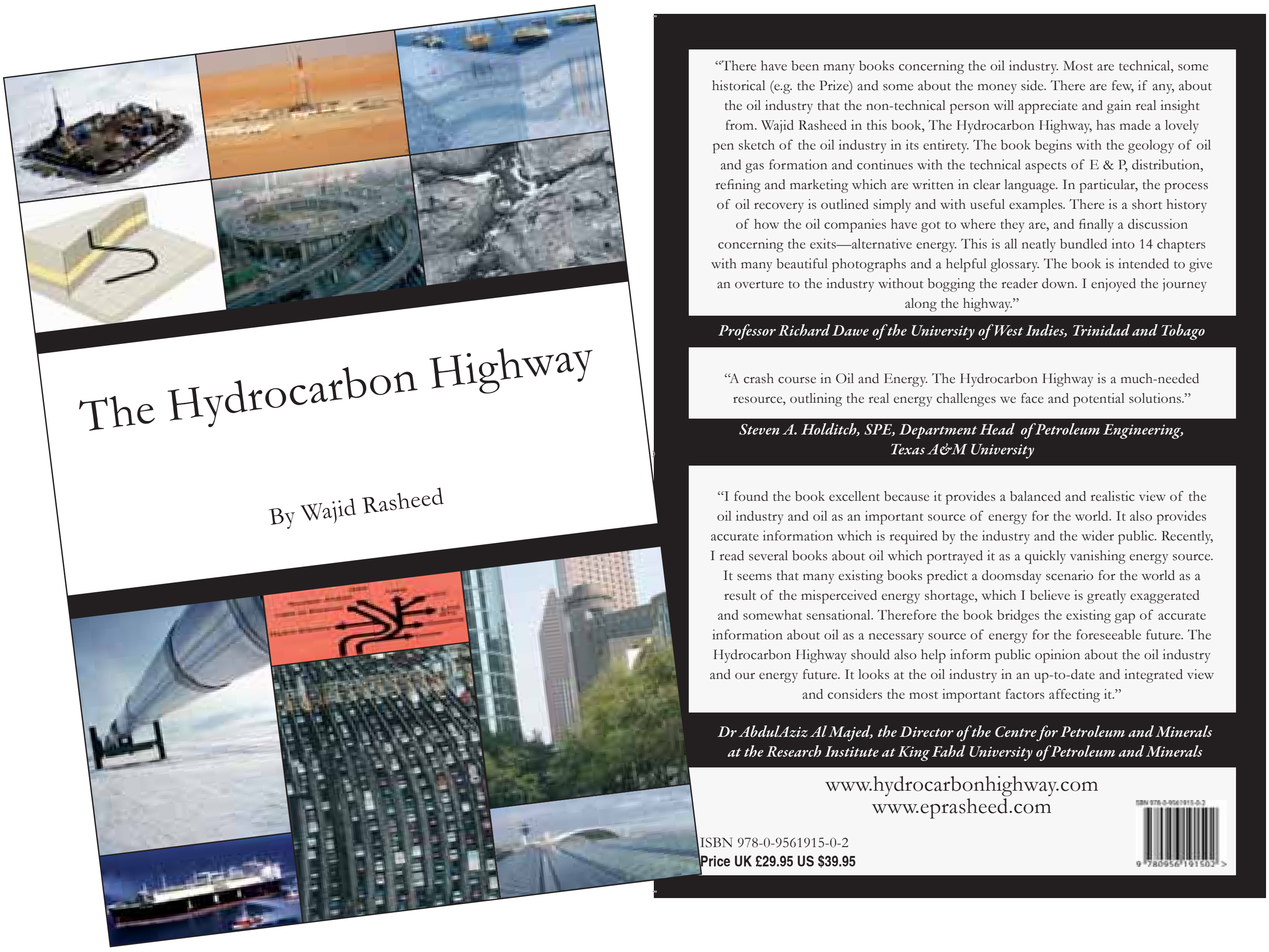
The Origin of Oil



This chapter is the foundation for understanding how oil and gas accumulations occur and what factors are involved in their discovery and development. A case history shows how analysis of oil and gas accumulations helps oil companies discover billion dollar assets.

Jurassic

If one looks at an outcrop or a core of the earth's formations, it's easy to see the natural beauty of differing rock types and deposited sedimentary layers. In the exploration for oil and gas, geologists or 'rock-doctors' often focus on 'ancient river deposits' or 'ancient marine reefs'. This refers to nature's legacy dating back through a geological timeline to when the continents were joined together in a single land mass known as Pangaea. Many sedimentary depositions and reservoir structures originated prior to continental drift when Pangaea was broken into separate land masses that

> "Bathymetry, the science of mapping seabeds, can show the connection of islands to land masses and the influence of ancient river systems in carrying sediment downstream to what were once marine areas or those that are underwater today."

form the continents we know today; for example, the western coastline of Africa and the eastern coastline of South America fit perfectly together. This explains the similarities found in oil and gas reservoirs in both areas today. Many millions of years ago, for instance, in the Jurassic and Cretaceous ages, eroded rocks, minerals and dead organic matter combined to form 'sediment' which was washed out onto seabeds. Imagine ancient heavy rainstorms at the top of a hill creating rainwater channels that collect sediment—minute particles of rock, earth and other debris—and deposit it into rivers which finally run to the sea[1].

Mapping Seabeds

Bathymetry, the science of mapping seabeds, can show the connection of islands to land masses and the influence of ancient river systems in carrying sediment downstream to what were once marine areas or those that are underwater today. Currents and waves spread sediment over many miles with larger heavier grains staying close to the river mouth, while lighter smaller grains are deposited further away. Combined with the dips, basins and platforms on the seabed, depositional patterns and dunes are created with certain areas accumulating massive organically-rich deposits of what was once marine life. It is for these reasons that marine sedimentary rocks interest rock-doctors (see Figure 1). These sediments are often linked to river systems, either existing or ancient. This is the reason why so much exploration is concentrated in the various offshore gulfs worldwide. Almost all of the easily accessed inland and deltaic reservoirs have been discovered[2].

Wind can also erode, transport and deposit rock particles and debris. Wind is particularly effective in arid areas and where there is a large supply of unconsolidated sediments. Although water is much more powerful, Aeolian or wind-based processes are important in deserts where they can form vast sand dunes. Aeolian deposition occurs once a sand dune becomes compacted and hardened forming a consolidated sandstone. In the southern part of the Arabian Peninsula, a region called the Empty Quarter (Rub-al-Khali) because of its lack of life, vast dunes can be found that routinely reach 93 miles (150 km) in length and 1,000 feet (300 m) in height (see Figure 2).

Plate Tectonics

The earth's surface and seabed is made up of two layers: the lithosphere and the asthenosphere. The lithosphere is the upper layer and it is quite rigid. It is broken up into numerous distinct tectonic plates (see Figure 3 opposite) which are moving, and this is exemplified by continental drift and seafloor spreading. Although

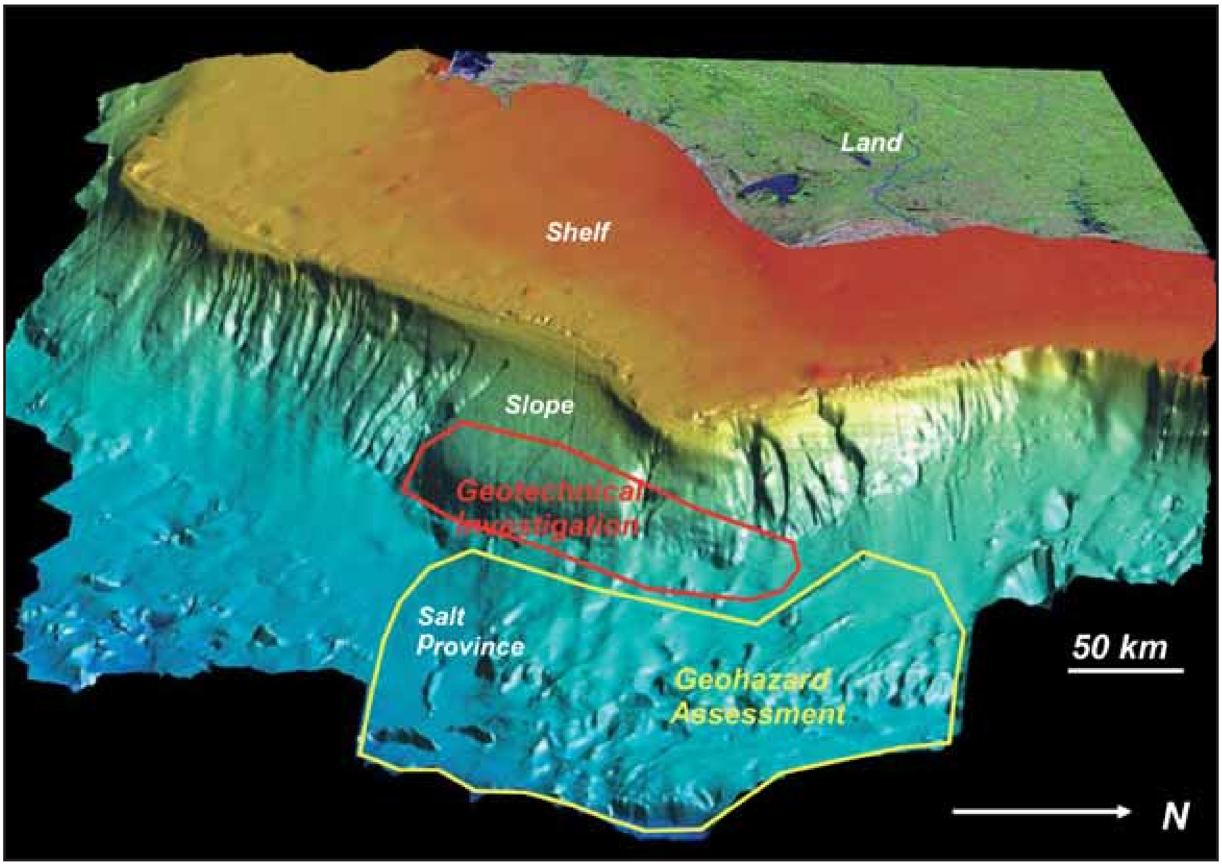


Figure 1 - Seafloor Under Investigation Offshore Brazil (Petrobras)

solid, the lower layer or asthenosphere is considered to behave as a fluid over geological time. It is this fluidity that permits the movement of the tectonic plates in all directions creating earthquakes, volcanoes, mountains, and oceanic trenches along plate boundaries.

Deposits

Over geological time, ancient river systems carried and deposited millions of tonnes of sediment as they ran their courses to river outlets, deltas or gulfs. In order for sediment to be deposited, a low-lying area called a basin is required. The largest basins are the ocean basins, which currently cover about 70% of the earth's surface. In the past, however, the sea level often changed and the continents were covered by shallow seas (referred to as epiric or epicontinental seas). When sea levels rise to invade the continents, this is referred to as a transgression. Major transgressions occurred during the Cretaceous era, and from the early Cambrian through Mississippian eras. Plate tectonic movements create basins, and even the large transgressions appear to be related to tectonic factors, as increased spreading of ocean basins changes their configuration and leads to flooding of the continents[3].

Layers of Earth

Over time, continuing deposits eventually formed numerous layers of sedimentary rock. These were pushed deeper and deeper under the seabed. Each successive layer (younger deposits) increased the pressure on earlier layers (older deposits) and tectonic plate movement deformed the layers creating folds, hills (anticlines) valleys (synclines), unconformities (eroded areas) and faults[4].

The Occurrence of Sedimentary Rocks

Sedimentary rocks have an average thickness of about 6,000 ft (1,800 m) on the continents. This thickness is quite variable; for example, some areas such as the Canadian Shield, have no sedimentary rock cover, while other areas such as the Louisiana and Texas Gulf coasts, have more than 65,600 ft (20,000 m) of

Figure 2 - Exploratory Rig in the Empty Quarter, Saudi Arabia (Saudi Aramco)

Figure 3 - Image of Tectonic Plates (Courtesy of British Geological Survey)

Name of Particle	Size Range	Scale	Loose Sediment	Consolidated Rock
Boulder	>256 mm	<-8	Gravel	Conglomerate or Breccia (depends on rounding)
Cobble	64 - 256 mm	-6 to -8		
Pebble	4 - 64 mm	-2 to -6		
Granule	2 - 4 mm	-1 to -2		
Very Coarse Sand	1 - 2 mm	0 to -1	Sand	Sandstone
Coarse Sand	0.5 - 1 mm	1 to 0		
Medium Sand	0.25 - 0.5 mm	2 to 1		
Fine Sand	0.125 - 0.25 mm	3 to 2		
Very Fine Sand	0.0625 - 0.125 mm	4 to 3		
Coarse Silt	0.031 - 0.625 mm	5 to 4	Silt	Siltstone
Medium Silt	0.016 - 0.031 mm	6 to 5		
Fine Silt	0.008 - 0.016 mm	7 to 6		
Very Fine Silt	0.004 - 0.008 mm	8 to 7		
Clay	<0.004 mm	>8	Clay	Claystone, Mudstone, Shale

Table 1 - Grain Sizes Table (After Prof. Stephen A. Nelson)

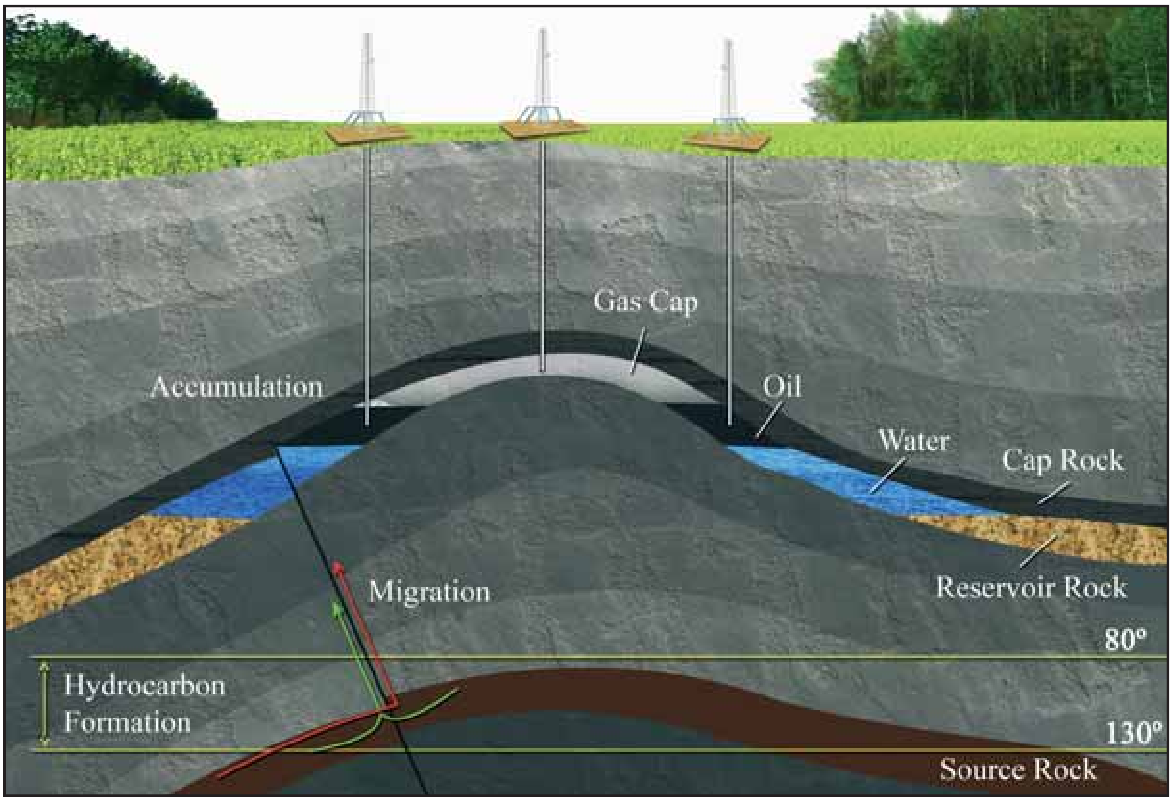
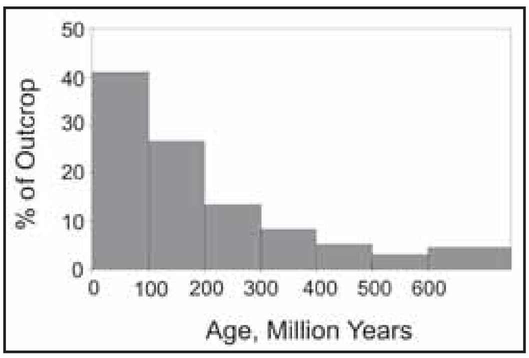


Figure 4 - The 'Window' for the Formation of Oil and Gas

> Because carbonate minerals in general are soluble in slightly acidic waters, they often have high porosity and permeability, making them ideal reservoirs for petroleum.

sedimentary rock cover. Generally, about 66% of all continental areas have a cover of sedimentary rocks.

The graph below illustrates that as sediment gets buried it avoids further erosion; hence, older sedimentary rocks show less exposed outcrop area than younger sedimentary rocks. More than 40% of the exposed sedimentary rocks are younger than Cretaceous in age.



Types of Sedimentary Rocks

Table 1 shows typical rock grain sizes. There are three basic types of sedimentary rocks:
1. Siliclastic sedimentary rocks are formed by the accumulation of mostly silicate mineral fragments. These include most sandstones, mud rocks, conglomerates, and breccias.
2. Chemical sedimentary rocks are formed by direct chemical precipitation from water. While some limestones and cherts may form in this manner, evaporite deposits consisting of halite, gypsum, and other salts are the most common.
3. Biogenic sedimentary rocks consist of fragments of particles produced by precipitation from once-living organisms. Most of these rocks are limestones and cherts.

95% of all sedimentary rocks consist of sandstones (made up of sand-sized fragments), mudrocks (made

Figure 5 - Pitch Lake at La Brea, Trinidad and Tobago (EPRasheed)

up of silt and clay-sized fragments) and carbonate rocks (made up of mostly calcite, aragonite, or dolomite). Mudrocks constitute 65% of sedimentary rocks, while sandstones make up 20% to 25% and carbonate rocks 10% to 15%.

Carbonate rocks largely consist of two types of rocks:

1. Limestones which are composed mostly of calcite ($CaCO_3$) or high magnesium calcite [$(Ca, Mg)CO_3$], and
2. Dolostones which are composed mostly of dolomite [$Ca Mg(CO_3)2$]

Because carbonate minerals in general are soluble in slightly acidic waters, they often have high porosity and permeability, making them ideal reservoirs for petroleum. It is for this reason they are well studied[5].

Limestone can easily be recognised in hand specimens or outcrops because of its high solubility in hydrochloric acid (HCl). A drop of acid placed on the rock will cause it to fizz due to the generation of carbon dioxide (CO_2) gas. A dolostone, on the other hand, will not fizz until a fine powder is made from the rock or mineral.

Source Rock

For oil and gas to form, the deposits of organic matter must be converted to hydrocarbon compounds. A 'window' or specific set of conditions is required for the formation of oil and gas (see Figure 4 opposite). Even today, the formation of oil and gas as a process is not fully understood but the prevalent theory is that time, pressure and heat c onvert decomposed marine life into elemental hydrocarbons. Within a given rock structure, the younger deposits or later layers form 'overburden' pressure conditions. Additionally, each layer has a given temperature profile according to the True Vertical Depth (TVD) at which it is located. The general rule is: the greater the depth, the higher the temperature. These factors combine to form oil and gas deposits in certain rocks known as 'source-rock', which can often be seen in certain oil and gas provinces in outcrops[6].

> "From their origins deep within the source beds, hydrocarbon molecules are squeezed by immense pressures caused by the overlying sediments similar to water from a sponge."

Migration

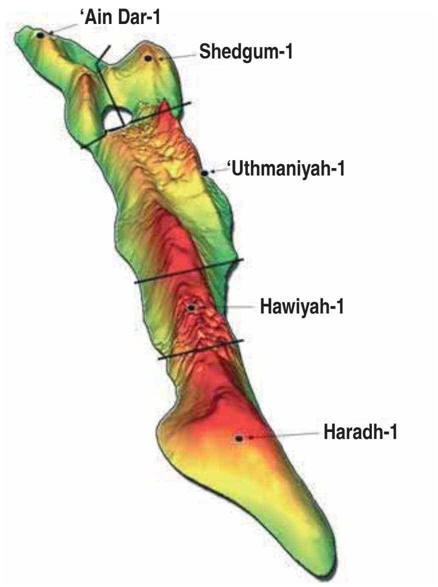
From their origins deep within the source beds, hydrocarbon molecules are squeezed by immense pressures caused by the overlying sediments similar to water from a sponge. They migrate to water-saturated porous and permeable beds where, being lighter than water, they start to rise. As they rise, they contact other hydrocarbon molecules and coalesce into droplets that keep rising until they encounter an impermeable layer called a cap rock. There, they accumulate, forming a reservoir.

Occasionally, the hydrocarbon makes it all the way to the surface without being trapped, forming a natural seep. It has been suggested that Christopher Columbus had moored off Trinidad to re-coat boats with pitch from La Brea (see Figure 5). The discovery well drilled by Colonel Drake in Titusville, Pennsylvania, US in 1859 was said to have been encouraged by a seep the Indians pointed out to the Colonel. The natives had been using the oil as pitch to waterproof their canoes and dwellings. Much of the tar blobs found on beaches have surfaced from natural subsea seeps.

Cap Rock

For oil and gas to accumulate, and to prevent it from subsequently dispersing, a trap is required. Usually, this is an impermeable layer known as 'cap rock' that seals off oil and gas deposits ensuring that the oil and gas remains in place, until it is tapped by the drill bit, or subjected to other geological forces.

Climate changes, weathering, glaciers, volcanic eruptions, river flooding and other natural forces can change or erode surface rocks. Consequently, the depths, thickness and tilt of the layers vary from place to place. Buried layers of salt, created by the evaporation of seas and lakes, can be squeezed by pressure loads or made to flow with heat. Due to its relatively low density compared to other rocks, salt will flow and rise, often forming domes and distorting the overlying layers. Tectonic forces over time can cause upheavals that result in the rock folding, fracturing or faulting. These subsurface movements and changes can create or destroy traps, which, when combined with factors such as timing, temperature and pressure, will determine the existence of hydrocarbon reservoirs[7].



Ghawar helped catapult Saudi Arabia into its role as the world's leading oil producer. The super-giant field is 178 miles in length and consists of five contiguous oil fields from north to south: 'Ain Dar, Shedgum, 'Uthmaniyah, Hawiyah and Haradh.

Figure 6 - Representation of Ghawar Field (Saudi Aramco)

Cap rock may be many layers higher than the original source rock, as oil and gas will always seek to leak or migrate upward unless it is stopped. Cap rock also plays a fundamental part in maintaining reservoir pressure.

Pitch Lakes

Pitch lakes are an instructive example of both reservoir pressure and the tendency of oil and gas to 'leak' to the surface of the earth. In this case, a dense heavy bituminous form of oil which is chemically attracted to minerals such as clay has 'flowed' to the surface in channels. Pitch lakes, tar sands or oil and gas seeps, were well known to ancient man who used the oil for a variety of uses from medicine to basic lighting. The term 'snake oil salesman' arose from the early pioneers who attributed healing powers to the 'surface oil'.

Driving Force

Underground pressure is the primary mechanism that drives oil and gas to flow to surface. The pressure of hydrocarbon reservoirs, prior to being tapped by the drillbit, is similar to that of an unopened bottle containing a fizzy drink. If you shake the bottle and immediately open it, due to the built-up pressure, a certain volume of liquid will be driven to the bottle top and spill-over. Known as a depletion drive, this is similar to the natural pressure of an oil or gas reservoir and can be exemplified by what were historically known as 'gushers'. For decades now, reservoir pressures have been carefully controlled for health, safety and environmental reasons and not least due to the value of the oil. Primary pressure, however, cannot be maintained indefinitely. Depending on the rate of depletion, the reservoir's pressure will drop, requiring secondary means of production[8]. It is always the case that producing fields see a reduction in the natural pressure or 'fizz' that drives hydrocarbons to the surface.

However, other drive systems exist also. These range from water drive which is by far the most common and prolific, the combined water drive with an expanding gas cap and the gravity drive. The depletion drive is very short-lived whereas water drives can be near infinite. The drive systems are detailed in *Chapter 9: Mature Fields*. Each one affects the production of oil and gas in a different way and this ultimately determines reservoir recovery factors.

Porosity and Permeability

Although people may perceive that there are large underground lakes or caverns of hydrocarbons, this is not true. Oil and gas is stored in tiny voids, called pores, within the reservoir rock which together may extend several hundred feet horizontally or vertically; for example, the world's largest oilfield, Ghawar in Saudi Arabia, has a reservoir rock that is approximately 178 miles (280 km) long[9] (see Figure 6).

> "Minute channels are created in the formations and, due to the pressurised nature of oil and gas and their relative lightness, there is always a tendency for the oil and gas to rise."

The three rock classes—source, reservoir and cap—help to explain two key concepts. Firstly, the sedimentary process explains why oil and gas are contained in minute rock spaces or pores (porosity) and not in caverns. Imagine a dry sponge placed over water. The water is drawn in and contained within the voids of the sponge. This is why porosity is defined as the percentage of 'voids' in a volume of rock. Secondly, sedimentation shows the ability of a fluid to 'seep' or 'flow' through a given formation (permeability). Minute channels are created in the formations and, due to the pressurised nature of oil and gas and their relative lightness, there is always a tendency for the oil and gas to rise. This is illustrated by the migration of oil and gas from a source rock to a porous reservoir rock[10].

Permeability can be visualised by thinking of a coffee machine, and ground coffee being packed into an espresso chamber. Under pressure, hot water flows or trickles through creating coffee. The water-flow through the porous coffee grinds is due to permeability, which is the relative interconnectivity of the pore spaces in the coffee pack. If we continue to pack in more coffee, a point is reached where the compaction (the equivalent being cementation in formation) is so great that it is progressively harder for coffee to flow through.

The ease or difficulty of 'flowability' is measured in 'millidarcies' (after Henri Darcy, a French scientist who promulgated Darcy's Law governing fluid flow through porous media in 1856).

Although porosity and permeability are key attributes of reservoirs, they are the most misunderstood concepts in reservoir engineering. Low permeability can mean that large reserves may not be produced economically, or even physically. Tight reservoirs are those that have low permeability. There are rocks (oolites) that have lots of porosity, but no permeability. Conversely, there are fractured formations that have little porosity, but flow like a fire hose because of fracture permeability. Porosity also explains why we say that not all reserves are recoverable; for all oil and gas to be recovered, we would have to extract the rock itself, and literally squeeze out every drop. Given that vertical depths of reservoirs routinely exceed 5,000 ft (1524 m) and can reach more than 25,000 ft (7620 m), it may not always be economically possible to pursue such targets[11].

Reservoir stimulation is a synthetic way to increase porosity and/or permeability. Due to their high solubility in hydrochloric acid (HCl), limestone

Figure 7 - A Stratigraphic Column in StatoilHydro Offices (EPRasheed)

Figure 8 - Outcrop In Bahrain Shows a Sedimentary Sequence (EPRasheed)

> "Geological mapping and geophysical surveys allow oil companies to characterise acquired acreage and the age and sedimentation patterns of the rock formation contained therein."

reservoirs are often 'acidised'. The acid pumped into the reservoir etches channels which improve production. For sandstone reservoirs, specialised fluids are pumped into the formation until it literally cracks open, thereby permitting better flow.

Sands of Time

With the passage of time, the land and seas holding oil and gas accumulations became subject to territorial jurisdiction and were bid for as leases or exploratory blocks. Such blocks (see *Chapter 6: Properties, Players and Processes*) have led to the discovery of famous fields and formations such as the Austin Chalk, Brent, Ghawar and Shtokman. Commercial quantities of petroleum occur almost exclusively within sedimentary rocks (sandstones, limestones and, rarely, claystones). Some of these deposits became famous as they were associated with crude oil or gas production such as the Kimmeridge clay in the UK North Sea, the Khuff limestone in Saudi Arabia and the Jurassic sandstone of the Shtokman field in Russia.
To summarise the origin of oil:

1. Hydrocarbons are formed by decomposing organic life subjected to temperature and pressure, while sealed by a layer of impermeable rock. This leak proof seal ensures that the hydrocarbon reservoir is maintained until it is tapped by the drill bit.
2. Source rocks need to be, or have been, in the right range of depths (and hence temperature) for sufficient time for the deposits to change into oil or natural gas. A source rock has massive organic deposits.
3. Porous reservoir rocks can exist above or below the source rocks.
4. Impervious cap rocks lie above the reservoir rocks.
5. Traps are required for the hydrocarbons to accumulate.

Geological and Geophysical Mapping

Geological mapping and geophysical surveys allow oil companies to characterise acquired acreage and the age and sedimentation patterns of the rock formation contained therein. This process of characterisation can be reconstructed as a visual earth model that delineates the position and shape of the structure including anticlines, faults-stratigraphy, structure.

It is useful to distinguish between the terms 'reservoir description' and 'reservoir characterisation'. The former is the means by which the reservoir is described (using

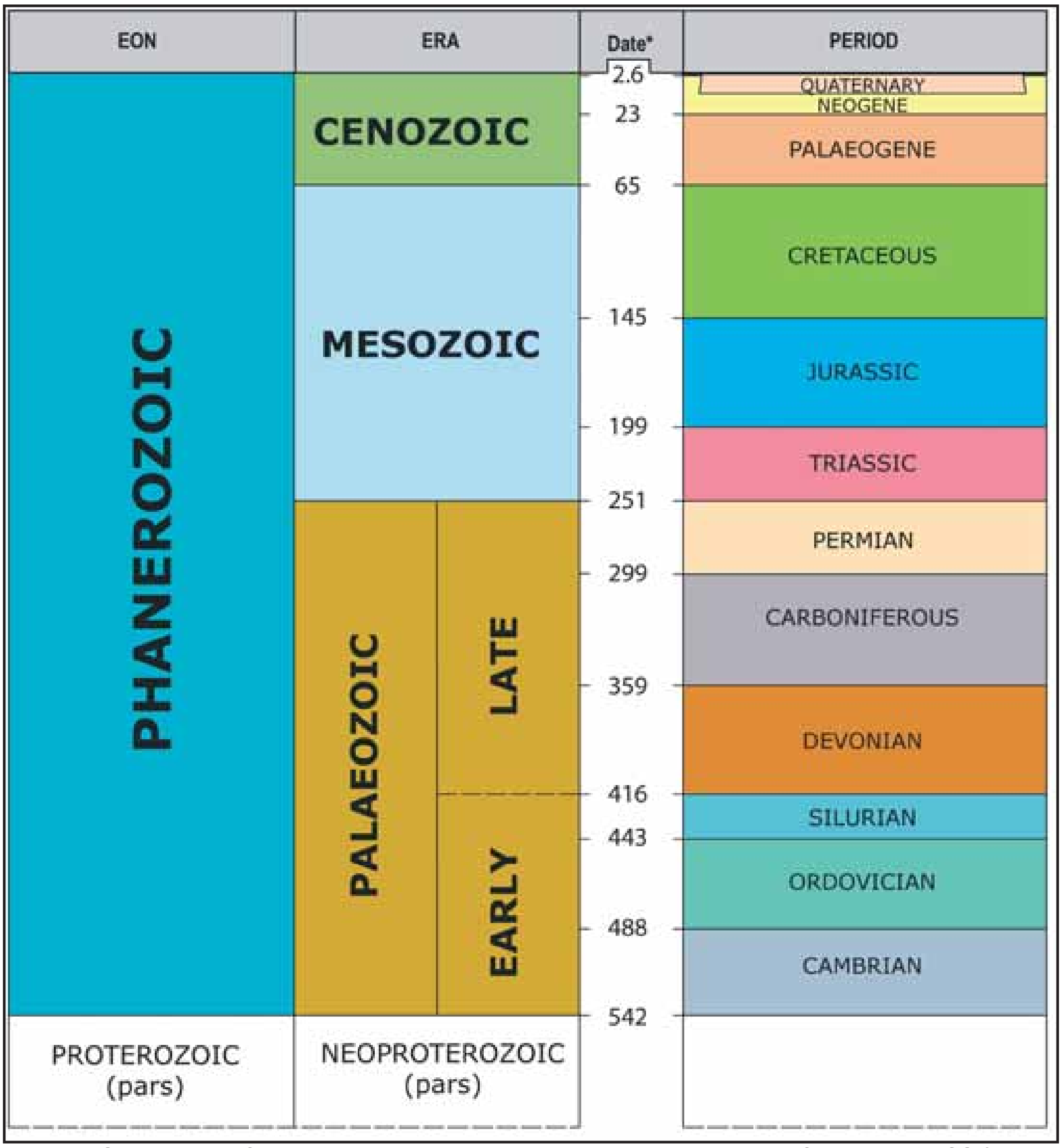


Table 2 - Stratigraphic Chart of Rock Types and Age in the United Kingdom. Courtesy of BGS (British Geological Survey)

observable parameters i.e. models), while the latter explains how it will behave under production and includes petrophysical parameters.

Geophysics is the study of the earth by quantitative physical methods—principally by measuring the gravitational, magnetic, electrical and seismic-velocity properties of the earth's surface and interior. The principal objective of geophysics is exploration, i.e. searching for subterranean structures that could trap and hold hydrocarbons. Recently, geophysics has been expandedto include characterisation of reservoir drainage patterns.

Measuring differences in rock properties provides information about the distribution and the structure of rocks at surface and at a given depth, and gives a three-dimensional (3D) picture of the earth's crust. Scientists use this information to better understand the evolution and structure of the earth, thus leading to more effective exploration for hydrocarbons, water and mineral resources.

The most common types of surveys include:
• Gravity surveys
• Magnetic surveys
• Electrical surveys

> Geophysics is the study of the earth by quantitative physical methods—principally by measuring the gravitational, magnetic, electrical and seismic-velocity properties of the earth's surface and interior.

- Electromagnetic surveys
- Radiometric surveys
- Seismic surveys
- Radar surveys
- Thermal imaging
- Geochemical imaging, and
- Downhole electrical and calliper surveys.

Surveys are conducted for different purposes: at regional scales to cover large areas both on the ground and from ships or aircraft and at local scales to cover specific sites such as mineral prospects on the ground, with marine or airborne instruments, or by using underground wellbores[12].

Stratigraphy

The stratigraphy of an area is obtained by measuring and describing the layers of rocks. This usually includes rock samples obtained using cores or cuttings or from outcrops (although this is becoming rarer due to the trend to deepwater and arctic areas).

Each rock sample is examined in the field and outcrop samples are taken to the lab where features are noted such as colour, grain sizes and mineral composition, fossil content, porosity and permeability. The samples are numbered and mapped so that their position in the sequence is known. They are then examined for small and large fossils by paleontologists.

In drill cuttings, only the microfossils are normally recovered since the large fossils are usually destroyed, although some may be recovered from cores. Sedimentologists will examine the samples to determine their nature and the environments in which they accumulated.

Geochemists will characterise changes in the organic material contained in rocks caused by time, heat and pressure. They will identify possible petroleum source rocks, assessing the burial history and hydrocarbon-bearing potential of the sediments. Geochemists also use spectroscopy logs to determine the elemental composition of the rocks, and subsequently their mineralogy. This information provides important clues as to the origin of the rocks, and enables cross-correlation with similar rocks in adjacent or 'offset' wellbores.

Stratigraphy, and the study of fossils, will help determine the geological age of rocks. This in turn enables the correlation of a given formation with other

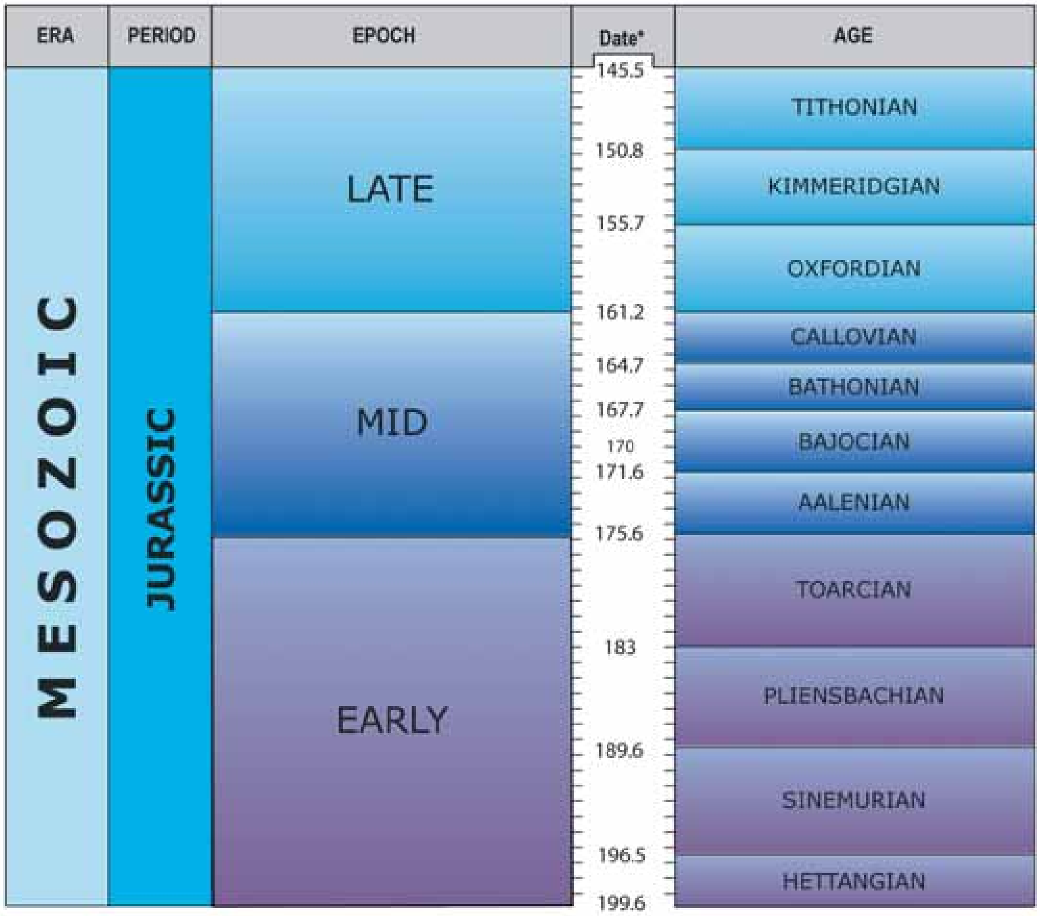


Table 3 - Mesozoic Stratigraphy of the UK. Courtesy of BGS (British Geological Survey)

areas, sections and boreholes. The stratigraphic sections are then correlated with each other for the area that is being mapped.

Stratigraphic Charts

A stratigraphic chart of the types and age of rocks can be created and is presented in Table 2 which shows the data for the UK. Different nomenclatures have been used by different geologists to describe the same age and type of rock found in other parts of the world. The most important time periods are from the Carboniferous era (299-359 million years ago), the Permian era (251-299 million years ago), the Triassic era (199-251 million years ago), the Jurassic era (145-199 million years ago [Table 3]) and the Cretaceous era (65-145 million years ago). It should be noted that there are some accumulations that are much older. Each of these periods is divided into distinctive sub-period epochs and then ages. The rock characteristics can also be grouped by changes in rock type. In the early Jurassic period in the Middle East, for example, the Hith, Arab, Jubaila, Diyab and Hanifa formations can be found. They can be dated by the fossils, including pollens, found in them. The depositional environments, together with the diagenesis (changes after deposition), are reflected in rock characteristics (e.g. how grain sizes or permeability change with depth)[13].

Distinctive rock types, known as facies, can be identified in the depositional layers. Changes occurring over a few metres within the reservoir provide clues as to the earth's history at that particular time and whether deposition occurred in a river delta, lagoon, seashore or desert. Each of these depositional environments creates unique properties of porosity, permeability and other reservoir characteristics which ultimately dictate hydrocarbon recovery.

> 'Marker beds' chronicle major events in the evolution of the earth; for example, huge volcanic eruptions blanketed huge areas of the earth's surface with characteristic ash that can be identified in cores and correlated with similar marker beds in other wells.

Facies analysis is used by petroleum geologists to derive a model of the subsurface, i.e. a reservoir description. This model of the multilayered reservoir is essential for the reservoir engineers when designing an optimum well completion or reservoir development and production policy. For instance, major intervals are often separated by seals of impermeable anhydrite or shale[14]. 'Marker beds' chronicle major events in the evolution of the earth; for example, huge volcanic eruptions blanketed huge areas of the earth's surface with characteristic ash that can be identified in cores and correlated with similar marker beds in other wells. This provides an indisputable reference that fixes the rock's age in geologic time. Paleomagnetics studies the residual effect of magnetic polarity changes in the earth's evolution where the earth's magnetic poles swapped polarity back and forth over eons of time. By understanding these factors, wells can be constructed using techniques and know-how that have already been proven in similar formations. This saves time and money allowing oil companies to reach production faster.

Identification of Rocks

There may be considerable doubt whether rocks, which are similar in both chemical and physical nature, are of the same geological age. The doubt can only be removed, if at all, by detailed laboratory work. Initially, rocks are compared to see whether the constituent minerals are chemically and physically similar. Even if they are, the same types may be repeated during geological time and a study of the fossils (paleontology) will be essential to reduce the uncertainties. Most species of fossil organisms lived for a considerable span of geological time before becoming extinct.

The study of fossilised pollen and plant spores or 'palynology' has become an important means of correlating rocks to geological time as they are often identifiable in rocks that present no other fossil content. This is because spores and pollen remain remarkably well preserved over geological time due to their almost indestructible husks. The palaeontologist will use X-rays and electron microscopes to compare fossil assemblages rather than individual species which allows

> "Renewables increase over time but do not displace petroleum entirely creating an inclusive energy model. Petroleum remains a permanent feature, its demand increasing from time to time as ethanol crops fall short or rainfalls fall below hydro-electric dam requirements."

for accurate correlation of fossils within geological time-scales. The ultra-microscopic plates from the bodies of minute marine organisms have complex shapes characterised by different geological periods and allow approximate geological dating of even small rock debris. Radiometric age-dating is also used and is based on estimates of the decay of radioactive isotopes of specialised minerals in the rocks.

Rock Analysis Using Cuttings

When an area is being drilled, the rock cuttings from nearly all exploration and appraisal wells are examined. Analysis of the cuttings encompasses fossil and minerals content including clays, geochemical content and the physical appearance or description of the rock (e.g. shape and size distribution of rock grains). These elements provide important clues as to the rock's age and depositional environment.

Rock Analysis Using Petrophysical Logs

Most wells have petrophysical logs routinely taken. Petrophysical logs are measurements of various electrical, nuclear and acoustical properties recorded as a function of depth and are made with special downhole tools.

Rock Analysis Using Cores

Coring is conducted using a drill bit that employs Polycrystalline Diamond Compact (PDC) cutting elements and has a hollow centre. This allows the cutting element to obtain a core of the formation that is being drilled. Cores are fragile and require special handling and storage techniques; however, they are not readily available.

They are often used as a complementary method of formation analysis and can be used to help calibrate logs and provide information for reservoir modelling. Consequently, cuttings, logs and cores are the production geologist's primary sources of data and enable them to describe the nature of the rocks that have been drilled (the stratigraphy—the sedimentary sequence in terms of lithological characteristics and rock properties)[15].

> The abundance of the trace metals showed a clear correlation and it was established that the oil from different reservoirs shared a common, deep source characterised by diffusive separation (regardless of the age, type or circumstance of the particular reservoir rocks).

Development

Despite development data being partial, and at times unreliable, key decisions to develop a prospect and spend millions of dollars have to be reached. Several appraisal wells are drilled to determine the size of the accumulation and to test the reservoirs for production capacity and quality. At this stage, geologists must work closely with the well log analyst, the reservoir engineers and production engineers. Refinements, or even gross revisions of the original reservoir assessments, are made as new data are obtained.

To plan a development of an oil or gas field, information is needed about the structure of the oil and gas reservoir such as the:

- Shape, size, volume and connectivity of the accumulation
- Porosity, pore geometry and permeability of the rock
- Fraction of the pore space filled with hydrocarbons
- Nature of the hydrocarbons
- Cost of wells, facilities, pipelines, installations etc.,
- Health, safety and environmental matters[16].

As a result of obtaining all the appropriate data, the oil company developing the field seeks to save millions of dollars and reach production faster by knowing how many wells to drill and where best to locate them. This is precisely what happened in the exploration and drilling project in the Dnieper-Donets Basin in the Ukraine as is indicated in the case history below.

Billion Barrel Case History

Careful study of the geology of the Dnieper-Donets Basin resulted in the discovery and development of 12 petroleum fields with oil reserves equal to 1.4 billion barrels of oil equivalent, the major part of which is produced from the Precambrian crystalline basement. These fields were discovered in a narrow strip approximately 22 miles (35 km) wide and 250 miles (400 km) long near the Northern Marginal Deep Fault where the oil and gas-bearing rocks are Middle and Lower Carboniferous period sandstones and Precambrian granites, amphibolites, and schists of the crystalline basement complex. This exploration project also generated the discovery of a new gas-producing

By examining micro-sized traces of pollen contained in the rock pores, scientists concluded that the oil migrated upwards to its present location from much older, deeper sediments.

area near Kharkiv for which the proven gas in place has been calculated to be 100 billion cubic metres (Bm^3).

The oil produced from all reservoirs was analysed for correlations of trace metallic elements; for example, the ratios of nickel and vanadium, and of either methane or nitrogen were measured. The abundance of the trace metals showed a clear correlation and it was established that the oil from different reservoirs shared a common, deep source characterised by diffusive separation (regardless of the age, type or circumstance of the particular reservoir rocks).

Paleontology in Oil and Gas Discoveries

Paleontological analyses of the oil in the Permian and Carboniferous sandstone formations demonstrated the presence of spore-pollen and other microphytofossils of the Devonian and Proterozoic ages, thereby establishing upward migration from deeper formations. By examining micro-sized traces of pollen contained in the rock pores, scientists concluded that the oil migrated upwards to its present location from much older, deeper sediments.

Bacteriology in Oil and Gas

The oil produced from the reservoirs in the crystalline basement rock of the Dnieper-Donets Basin has been examined particularly closely for the presence of either porphyrin molecules or 'biological marker' molecules, the presence of which used to be misconstrued as 'evidence' of a supposed biological origin for petroleum. None of the oil contains any such molecules, even at the parts per million (ppm) level. There is also research presently under progress, which has established the presence of deep, anaerobic, hydrocarbon metabolising microbes in the oil from the wells in the uppermost petroliferous zones of the crystalline basement rock in the Dnieper-Donets Basin.

These results, taken either individually or collectively, helped optimise the drilling and production strategy within the Dnieper-Donets Basin[17,18].

Now that we understand how oil and gas is formed, it is time to ask two important questions: Are we running out of oil? And given that oil and gas reserves are miles below ground, how are they actually measured?

> "Petrophysical logs are measurements of various electrical, nuclear and acoustical properties recorded as a function of depth and are made with special downhole tools."

References

1. See Issue 1 TTNRG (2004) – Why does Trinidad and Tobago have Oil? By Wajid Rasheed. (www.ttnrg.com)

2. Well known fact that the 'low-hanging fruit' or easy-to-produce reserves in land and shallow waters have been well characterised and produced.

3. The majority of world's oil is located in the Tethyan Belt, lying between the equator and mid northern latitudes; and running from Venezuela through the Middle East to China and Indonesia. Tethyan petroleum systems are characterised by facies deposited in tropical environments such as carbonate and evaporites, and prolific source rocks laid down in warm lakes and shallow epiric seas. However, about a third of global petroleum is in the mid to high northerly latitudes of the Boreal Realm. Though some petroleum systems rely on Palaeozoic source rocks originally deposited in low paleo-latitudes (e.g. Late Devonian shales of Timan-Pechora Basin), most are sourced from marine Jurassic-Cretaceous shales deposited in restricted rift basins in high paleo-latitudes. These include the world class source rocks of the Neocomian of the North Slope of Alaska and the Late Jurassic of the North Sea, Eastern Canada, and West Siberia. See Bradshaw Marita et al Oil from the South.

4. See Sedimentation in standard geology texts or country geological surveys such as the British Geological Survey.

5. Not just for these reasons but also because carbonates hold much of future reserves.

6. See Issue 1 TTNRG (2004) – Naparima Formation which is the source rock is easily visible in Naparima Hill, Trinidad and Tobago. See AAPG Explorer June 2003 Long studied outcrops in Spain that may hold secrets to understanding deepwater reservoirs are providing new clues, thanks largely to new 3-D laser technologies.

7. Oil shales did not make it through the 'Window' for the Formation of Oil and Gas. Oil shale/sands were not subjected to the depth, pressure and temperature

necessary to form crude oil. Therefore, their hydrocarbon content varies between that of coal and crude oil. Extraction efficiency depends on differing factors but generally 1 barrel of oil requires 1.5 to 2 tonnes of rock or sand. The total global resource of oil shales is order of magnitude greater than crude oil reserves. But extracting the energy value of oil shale is only valid at US $50 to $70. The industry is working on ways to reduce shale oil extraction costs.

8. See Horizontal Well Technology, Sada Joshi, p 49 Reservoir Engineering Concepts ISBN 0878143505. Drop a stone in a calm pond. As soon as the stone is dropped in the pond, one can see circular waves going outward. A similar phenomenon occurs when a well is put on production in a given drainage area. The pressure disturbance or loss is felt initially at the wellbore and it will take time before fluids furthest from the well start migrating to the well and as time progresses average reservoir pressure decreases. See Reservoir Engineering texts for detail of primary reservoir pressure curves and bottom-hole pressure.

9. See Saudi Arabia Oil and Gas Magazine Issue 8 2008 - Ghawar, Saudi Aramco. (www.saudiarabiaoilandgas.com).

10. See Pirson S.J., 1950, Elements of reservoir engineering: McGraw-Hill.

11. Economic conditions are moving targets dependent on oil prices and production technology. Finding and lifting costs themselves vary, ultimately it is the oil price and the cost of production technology that determines what is cost effective. Nonetheless an average of 65% of conventional resources are left underground.

12. Surveys help reduce drilling risk.

13. See Diagenesis of Carbonate Rocks: Cement-Porosity Relationships Friedman ISBN: 0918985366.

14. In drilling wells sub-salt GOM and Brazil the occurrence of impermeable Anhydrite and Shale beds is commonplace.

15. Cores are just one of the geologist's characterisation tools.

16. HSE will be statutory requirements set by lease agencies such as the Minerals Management Service (MMS) in the offshore US OCS or environmental authority IBAMA in Brazil.

17. Petroleum Geology and Resources of the Dnieper-Donets Basin, Ukraine and Russia, by Gregory F. Ulmishek. U.S. Geological Survey Bulletin 2201-E.

18. The Drilling & Development of the Oil & Gas Fields in the Dnieper-Donetsk Basin, by V. A. Krayushkin, T. I. Tchebanenko, V. P. Klochko, Ye. S. Dvoryanin Institute of Geological Sciences and J. F. Kenney Russian Academy of Sciences.