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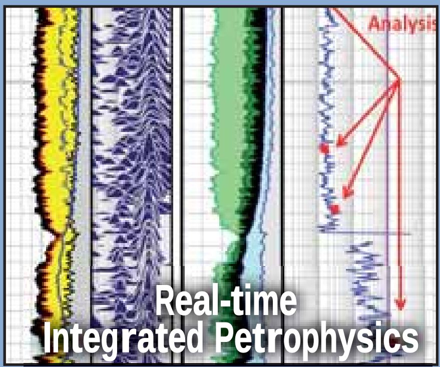
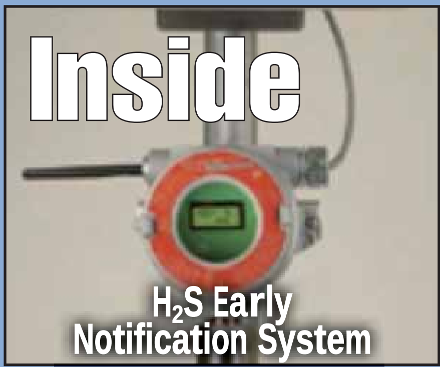
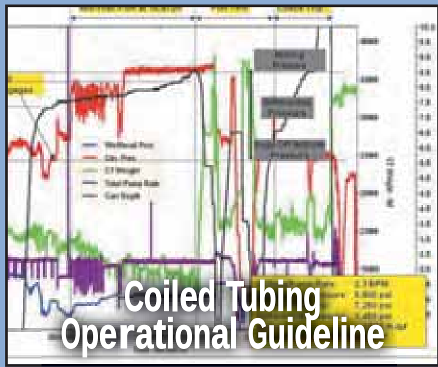




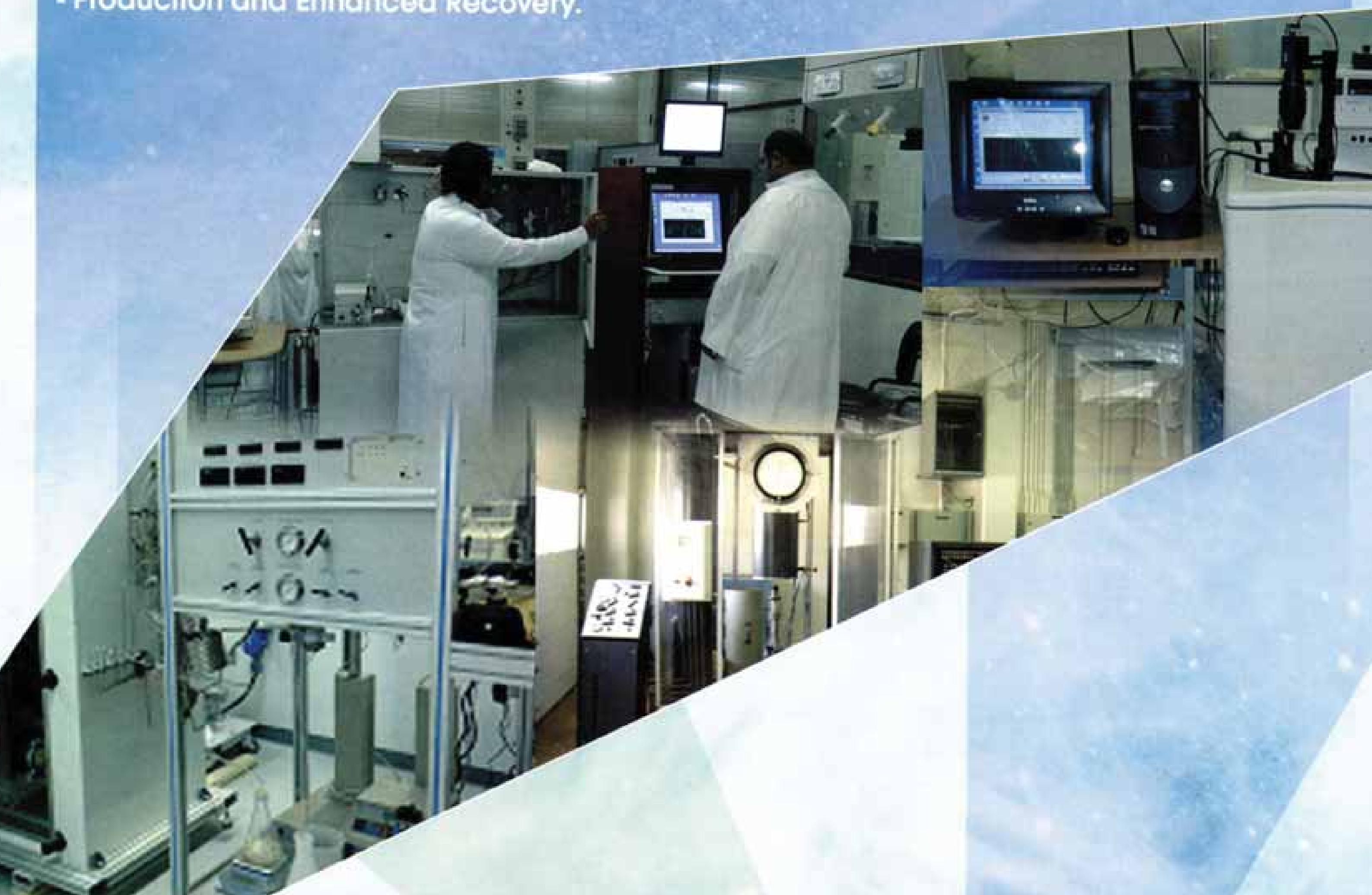


مدينة الملك عبدالعزيز
KACST للعلوم والتقنية

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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EPRASHEED
signature series
2012 – Issue 28
Saudi Arabia oil & gas
Saudi Arabia Oil & Gas (Print) ISSN 2045-6670
www.saudiarabiaoilandgas.com
Saudi Arabia Oil & Gas (Online) ISSN 2045-6689

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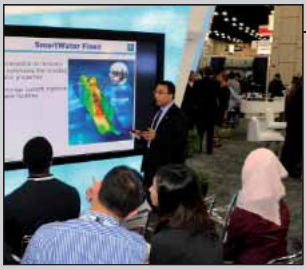

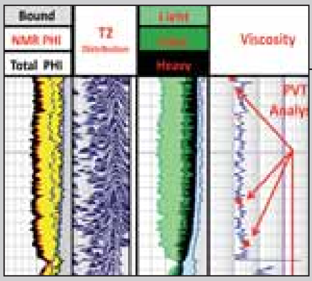

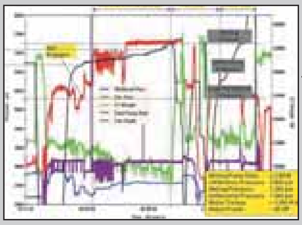

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Saudi Arabia Section

SPE ANNUAL TECHNICAL SYMPOSIUM & EXHIBITION

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The Society of Petroleum Engineers (SPE) - Saudi Arabia Section is pleased to invite you to submit a paper proposal for the 2013 SPE Annual Technical Symposium & Exhibition, taking place May 19-22, 2013, at Seef Center in al-Khobar.

The technical program committee accepts abstracts under Exploration and Production (E&P), highlighting:

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The ATS&E is a platform for regional and international professionals, academics, and researchers to exchange views, expertise and knowledge, and to promote the latest industry research and technology. I look forward to your participation in this event.

ATS&E

Ali Habbtar, Chairman
2013 SPE Annual Technical Symposium & Exhibition
Email: ali.habbtar@aramco.com

The submission deadline for abstracts is December 7, 2012, and authors will be notified of proposal acceptance by January 9, 2013.

SUBMIT ABSTRACTS NOW

HE Naimi Leads Tour of Mega Projects

DHAHRAN, 16 October 2012

His Excellency Ali Ibrahim Al-Naimi, Minister of Petroleum and Mineral Resources and Chairman of the Board of Directors of Saudi Aramco, on October 16 led board members on a tour of some of the Company's mega projects.

HE Naimi and Saudi Aramco Board members including Khalid A. Al-Falih, president and CEO, visited Karan Gas field, the company's first offshore non-associated gas project, and inspected its production platforms in Arabian Gulf waters.

Karan, which has helped to boost the Kingdom's gas production by 18 percent, was completed ahead of schedule and below budget, reaching its full production capacity of 1.8 billion cubic feet per day (bcfd) during the peak summer consumption period. HE Naimi and the board members also toured the gas production facility at Khursaniyah.

After the visit to Karan, the Company's board members proceeded to the Wasit Gas Project to review and check on its progress. At Wasit, Company officials confirmed that the project is proceeding as scheduled with inauguration set for mid-2014.

"At Wasit, Company officials confirmed that the project is proceeding as scheduled with inauguration set for mid-2014."

> "Through such projects, Saudi Aramco will help enhance its growing role in the energy sector in-Kingdom and overseas, and serve as an enabler of opportunities in the Kingdom's economy and in the diversification of investments in the downstream sectors, particularly in refining and petrochemicals."

With an estimated production capacity of 2.5 bcfd, the Wasit Gas Project will increase the Kingdom's gas production capacity by 21 percent, and with Karan, both these projects will raise the Kingdom's gas output by approximately 40 percent.

These gas projects will help meet the Kingdom's rising demand for energy; support the Saudi economy's power, water and industrial sectors; and provide mining projects in Ras Al-Khair City with the gas and sulfur needed to produce aluminum, phosphate fertilizers and related manufactured goods.

During the tour with the Board members, HE Naimi launched the Manifa Field's reservoir water injection operations in preparation for first phase production of Arabian Heavy crude oil at an initial capacity of 500,000 barrels per day (bpd) in the first half of 2013, and which will gradually increase to 900,000 barrels per day by 2014.

The crude oil from Manifa will feed in-Kingdom refineries that are currently under construction, namely SATORP in Jubail, the joint venture with France's Total, and YASREF in Yanbu', the joint venture with Sinopec of China, and the upcoming Jazan refinery, which has received Board approval for financing, and the project's contracts are expected to be awarded in the coming weeks.

Through such projects, Saudi Aramco will help enhance its growing role in the energy sector in-Kingdom and overseas, and serve as an enabler of opportunities in the Kingdom's economy and in the diversification of investments in the downstream sectors, particularly in refining and petrochemicals.

Tour highlights:

• Karan produces 1.8 bcfd of gas, increases Kingdom's gas production by 18 percent.
• Wasit Gas Project on-schedule for mid-2014 start.
• Karan and Wasit to increase Kingdom's gas production by almost 40 percent.
• HE Naimi launches Manifa reservoir water injection operations in preparation for first phase production in first half of 2013.

Contractors Selected for the Jazan Project

DHAHRAN, 21 October 2012 – Saudi Aramco has completed the contractor selection process for the engineering, procurement and construction (EPC) phases of the Jazan Refinery and Terminal, in the southwest part of the Kingdom of Saudi Arabia.

After completion of front-end engineering design (FEED) work in April 2012, competitive bidding for the EPC contracts took place, and it has concluded with the selection of Saudi Arabian and international contractors to implement the mega-project.

A robust and competitive process took place for the projects' major contract packages and the following companies are among the selected contractors:

- Petrofac Saudi Arabia Ltd. (Saudi Arabia)
- Hyundai Arabia Co. Ltd. (Saudi Arabia)
- Hanwha Engineering and Construction Corp. (Korea)
- SK Engineering & Construction Co. Ltd. (Korea)
- Tecnicas Reunidas (Spain)
- JGC Corporation (Japan)
- Hitachi Plant Technologies, Ltd. (Japan)

> "The Jazan Refinery will be synergized with a world-scale Integrated Gasification Combined Cycle plant that is currently at the FEED stage."

> "Scheduled for completion in late 2016, Saudi Aramco's Jazan Refinery and Terminal mega-project is expected to play a significant role in the supply of feedstock and fuels to support the growth of major industries in Jazan Economic City."

A signing ceremony for the major packages and contracts' awards is scheduled to be held in Jazan Economic City next month at the project site.

Scheduled for completion in late 2016, Saudi Aramco's Jazan Refinery and Terminal mega-project is expected to play a significant role in the supply of feedstock and fuels to support the growth of major industries in Jazan Economic City.

The Jazan Refinery and Terminal project is expected to create numerous economic benefits, including business opportunities for local enterprises and new job opportunities.

Jazan Refinery and Terminal Project

Saudi Aramco's Jazan Refinery and Terminal Project is a 400,000 barrel-per-day refinery with associated terminal facilities on the Red Sea near Jazan in the southwest part of the Kingdom of Saudi Arabia.

Scheduled for completion in late 2016, the refinery will process Arabian Heavy and Arabian Medium crude oils, and produce gasoline, ultra-low sulfur diesel, benzene and paraxylene.

The Jazan Refinery will be synergized with a world-scale Integrated Gasification Combined Cycle plant that is currently at the FEED stage.

The marine terminal will have the capacity to handle Very Large Crude Carriers (VLCCs) for the supply of crude oil to the refinery, and berths to support refined product exports from the refinery.

The Ministry of Petroleum and Mineral Resources had entrusted Saudi Aramco to build and operate the Jazan Refinery and Terminal, which is wholly-owned by Saudi Aramco and will become an integral part of its refining network to meet the Kingdom's energy demand and export surplus fuels to international markets.

Petroleum Engineers, Math Experts Join Forces

DHAHRAN, 21 October 2012 – The EXPEC Advanced Research Center (EXPEC ARC) Computational Modeling Technology Team (CMT) spearheaded an initiative to bring together the international mathematical community and petroleum engineering computational scientists in Istanbul, Turkey, at a recent conference on large-scale reservoir simulation.

For the first time, two influential professional organizations – the Society of Petroleum Engineers (SPE) and Society for Industrial Applied Mathematics (SIAM) – met to discuss mathematical challenges facing reservoir fluid-flow dynamics in large-scale models. The Istanbul Technical University was also instrumental in providing support.

"As we strive for finer resolution representing more physics, increased speed and new features in computational modeling and simulation of Saudi Aramco's giant reservoirs, particular challenges persist," said Ali Dogru, CMT chief technologist. "Mathematical models in fluid dynamics and flow through porous media play a critical role in developing and managing these reservoirs."

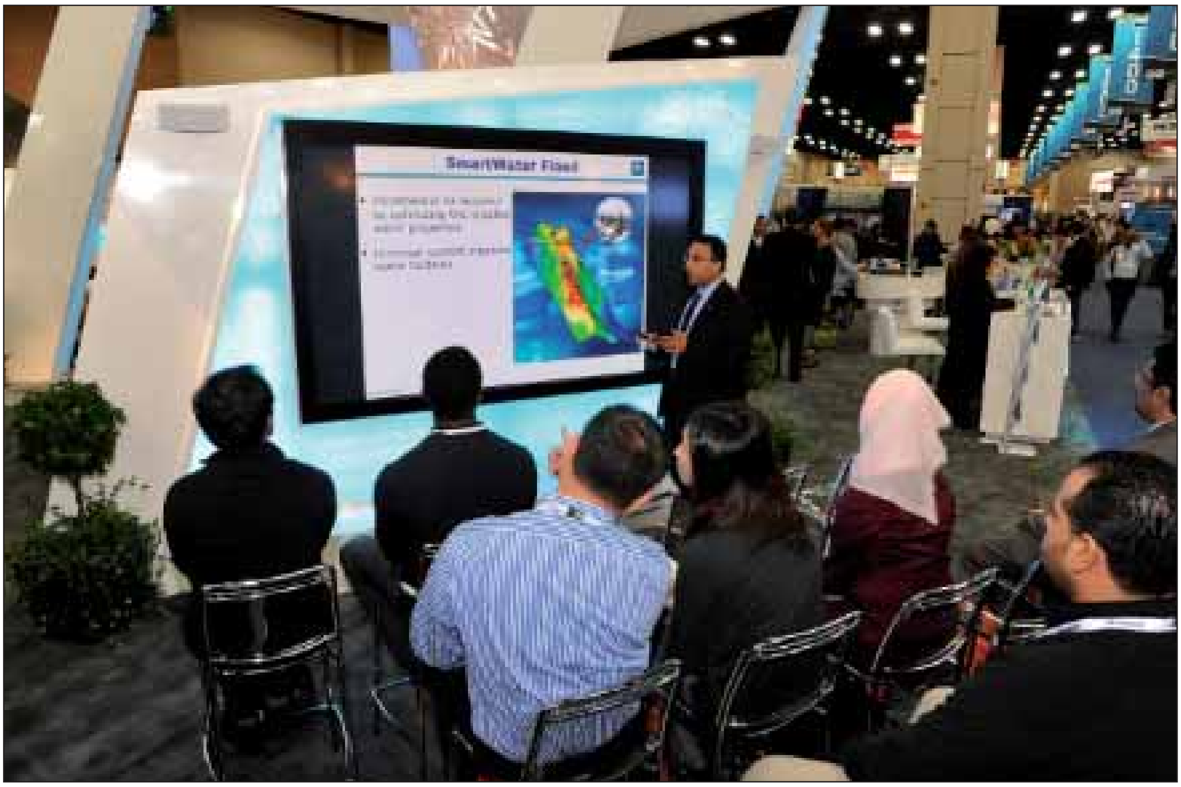
Dogru recognized the need to bring the two industries together to introduce computational modeling challenges to the international mathematical community to leverage new perspectives in joint research that will further advance the ability to accurately model and simulate fluid flow in the reservoirs.

"We have been collaborating with academia on specific mathematical aspects to enhance a variety of GigaPOWERS' features. However, a formalized introduction has been necessary to attract a critical mass to address a broader range of issues and bring new minds to our industry's endeavors," said Dogru.

As the initiator of the conference theme, Dogru led the conference as chairman. Co-chairs included David Keyes of SIAM and dean of the Division of Computer, Electrical, and Mathematical Sciences and Engineering, King Abdullah University of Science and Technology; Mary Wheeler, director of the Center for Subsurface at the Modeling Institute for Computational Engineering and Sciences at the University of Texas at Austin; and Sedar Celebi, head of the Computational Engineering Science Department at Istanbul Technical University.

A keynote speech was given by Samer AlAshgar, manager of EXPEC ARC, reflecting on the long-term vision of Saudi Aramco. "In alignment with EXPEC ARC's pursuits to broaden our research to bridge into and benefit from other industries, we look forward to delving into fresh collaborative research with many of the conference's mathematical experts," said AlAshgar.

SPE Conference Highlights



HOUSTON, 7 November 2012

Some of the brightest minds in the oil and gas industry recently gathered in San Antonio, Texas, for the 2012 Society of Petroleum Engineers (SPE) Annual Technical Conference and Exhibition.

Saudi Aramco's Mohammed Al-Qahtani, vice president of Petroleum Engineering and Development, opened the general session on behalf of conference chairman and Saudi Aramco president and CEO Khalid A. Al-Falih.

Al-Qahtani provided opening remarks to the panel session titled "Making Unconventionals Conventional", which featured four industry thought leaders, including: David Lesar, president and CEO, Halliburton; Mark Albers, senior vice president, ExxonMobil; Timothy Dove, president and COO, Pioneer Natural Resources; and Steve Holditch, director, Texas A&M Energy Institute. Each offered a perspective on the need to employ unconventional wisdom to the challenge of meeting the world's ever increasing demand for energy.

A few common themes emerged from the discussion:

1. The need for industry to better communicate to the public and key stakeholders the economic benefits of unconventional resource development.

2. The industry's continued commitment to environmentally friendly and sustainable development with regards to unconventionals.

> Al-Qahtani noted that the petroleum industry has always risen to challenges in exploration and production and that the key to addressing these challenges has been the timely development and deployment of new technology.

3. The need for industry to not only compete but also cooperate with more knowledge-sharing to advance technology and field development schemes.

4. The global potential of shale gas and other unconventionals toward unlocking supplies of oil and gas around the world.

Al-Qahtani noted that the petroleum industry has always risen to challenges in exploration and production and that the key to addressing these challenges has been the timely development and deployment of new technology. The phenomenal growth of shale gas production, for example, has been made possible by "out-of-the-box" technologies and practices, he said.

He also emphasized that the conference was about more than shale gas, tight oil or other unconventional approaches. "What faces our industry is more than just modifying a conventional enterprise to be able to produce from unconventional sources," he said. "It is not about an oil producer getting into shale gas. It is about transforming an entire industry and its various elements to operate in a new and dynamic environment."

Al-Qahtani, who serves as chairman of SPE's Executive Advisory Committee, concluded his remarks by encouraging the petroleum industry to raise its sights and aim higher. "Our brightest era is yet to come," he said.

Aramco Asia Regional Headquarters Opens in Beijing

BEIJING, 13 November 2012

Saudi Arabian Oil Company (Saudi Aramco), the fully integrated, global petroleum and chemicals enterprise, announced the official opening of Aramco Asia in Beijing, China, deepening its presence in one of the world's fastest growing regions, a move that underscores the strategic importance of Asia to the company.

Aramco Asia, which is a wholly-owned affiliate of Saudi Aramco and headquartered in Beijing, will serve as the business and cultural exchange portal between Saudi Aramco and China. The new head office in Beijing has two supporting branches in Shanghai and Xiamen.

"Our new Asia office here in Beijing will be a hub for facilitating our joint activities in general and in particular investment and other business opportunities arising from the capital projects in Saudi Arabia and Asia. The Kingdom is 'open for business' for Chinese and other Asian companies, as there are abundant opportunities across many sectors," Abdulrahman F. Al-Wuhaib, Saudi Aramco Senior Vice President, Downstream, said at the Aramco Asia inauguration ceremony on Monday in Beijing.

The new entity will provide services of crude oil and chemicals marketing, joint venture coordination, procurement, inspection, research and development, project management, human resources development and communications in the region.

"Aramco Asia brings together our business operations in this fast-growing region under one entity and be unified in carrying out Saudi Aramco's vision and strategy for Asia. Aramco Asia will play an important role and be part of the building blocks that will

> "Aramco Asia brings together our business operations in this fast-growing region under one entity and be unified in carrying out Saudi Aramco's vision and strategy for Asia."

contribute to Saudi Aramco's corporate transformation to become a global leader in energy and chemicals by 2020," said Dawood M. Dawood, vice president, Marketing, Supply and Joint Venture Coordination (MSJVC), Saudi Aramco, who led Saudi Aramco teams in implementing the company's strategy in the establishment of Aramco Asia.

More than 300 distinguished guests, including Chinese government officials, foreign embassies' ambassadors, top executives of energy companies, veteran energy experts and researchers from Chinese academia and institutions, as well as Saudi Aramco and Aramco Asia's long-term partners, attended the grand inauguration on Monday.

"Aramco Asia will offer a full range of services and resources for the handling and management of robust business between Saudi Aramco and our partners and companies in China, and the wider Asia region," said Mr. Sulaiman M. Ababtain, president, Aramco Asia, at the inauguration ceremony.

At present, Aramco Asia manages the interest of two joint ventures in China: Fujian Refining and Petrochemical Company, or FRPC, and Sinopec Senmei Petroleum Company Ltd. Both are located in southeastern Fujian province.

In addition, Aramco Asia is preparing to sell chemical products from FRPC to tap into China's chemical market, aligned with parent Saudi Aramco's goal to become a global leader in refining and chemicals by 2020.

Remarks at the Oxford Energy Seminar

By Khalid A. Al-Falih, President and CEO, Saudi Aramco.

OXFORD, UNITED KINGDOM, 20 September 2012 – "Ladies and Gentlemen, good afternoon. It's always a privilege to join this seminar – my fourth as CEO of Saudi Aramco. Robert Mabro and Nader Sultan: thank you for inviting me back and for making me feel most welcome, as always.

I flew in last night from the west coast of Saudi Arabia where our entire Executive Management team met over two and a half days to discuss our transformation plans for Saudi Aramco – an unprecedented event in our history. I say "entire team", but that's not quite true. I value this Seminar most highly so I made a special exemption for three of our team to attend.

I know you've had a busy, but I hope educational and enjoyable, two weeks. I'm also conscious that by now you have heard industry assessments and forecasts from a variety of angles, delivered by a range of preeminent industry leaders and analysts.

A common thread in virtually every presentation is that this great industry of ours is in the midst of profound change, and we're all having to face up to the various challenges this brings. Saudi Aramco is no exception, and I'd like to offer our own unique perspective on the changing landscape as well as talk about some of the profound changes the company is making in order to thrive in this new era.

Paradigm Shift In The Global Energy Landscape

At Saudi Aramco, our view is that a paradigm shift is underway that is significantly changing the global energy picture from what was commonly perceived only a few years ago. I'd like to touch on four strategic areas, or sweeping new realities as I prefer to call them, where this paradigm shift is most clearly in evidence.

First, downward pressure on global energy demand, and oil demand in particular.

Before the world was rocked by the financial crisis of 2008, there had been an expectation of rapid and sustained growth in energy and oil demand. In just four years, that perception has been significantly altered.

We are seeing downward pressure on demand as life-style and demographic changes take hold, while environmental pressures and government policies (including potential carbon taxes) continue to work against oil in particular and fossil fuels in general, impacting their demand growth, particularly in maturing advanced economies. For instance, there has been a welcome emphasis on higher energy efficiency in all sectors, especially in transportation.

In the United States, for example, which is the largest transportation fuels market in the world, aggressive new CAFE standards aim to raise mileage efficiency for light vehicles from around 30 miles per gallon today to around 55 miles per gallon in 2025; an improvement of more than 80 percent. Whether or not these targets are fully achieved, the ongoing trend in vehicle efficiency improvements will clearly exert downward pressure on oil demand.

Then there's the impact of the global economic turmoil, as a consequence of which global economic

> "At Saudi Aramco, our view is that a paradigm shift is underway that is significantly changing the global energy picture from what was commonly perceived only a few years ago."

growth may not return to pre-crisis levels at least for several years – what some economists are calling the "new normal." Demand growth figures have varied in recent years.

But demand this year is expected to increase by only a modest 850 thousand barrels per day, or less than 1 percent, whereas growth averaged more than 2.3 percent between 1965 and 2010.

Moreover, 20 percent of this incremental demand is the result of Japan's nuclear power outages. Furthermore, last year's global demand forecasts out to 2030 – by both the EIA and IEA – were 8 to 9 percent lower than the same forecasts in 2007. All of this is clear evidence of a slowdown.

Second, long-standing fears about our industry's ability to keep the world supplied have been well and truly laid to rest.

In just the past five years, despite consuming close to 90 million barrels a day, or a total of 165 billion barrels over just the past five years, global proven oil reserves have increased by more than 200 billion barrels. That's like discovering another Kuwait and UAE combined! As you know, this is primarily due to the application of improved technologies to unconventional and heavy oils, but new oil provinces are also appearing on the map.

The story of natural gas is even more spectacular. Current proven reserves of gas are more than 7,300 trillion cubic feet, enough for 64 years globally. But total conventional and unconventional resources are believed to be in the range of more than 28,000 trillion cubic feet – split broadly down the middle – which is enough for some 250 years at current consumption rates.

Nowhere has this change in oil and gas supplies been more radical than in the US. The National Petroleum Council indicates that an estimated 180 billion barrels of tight oil could be recovered with existing technologies. That amount would climb to more than one trillion barrels if oil shale acreage reaches its full potential. And of course similar developments are not restricted to the US.

In short, misconceptions about the worldwide scarcity of global oil and liquids supplies have given way to a sense of abundance, and our industry should be proud.

Third, falling investment in renewables.

This has not been an encouraging year for renewable energy. Global investment in green energy projects plunged to $25 billion in the first three months of this year (the lowest level since the global financial crisis), and though they increased by over 50 percent in Q2 that was a still a decline of over 25percent on the same quarter last year.

The reasons are all-too familiar. In Europe, many countries are nervous about their debt levels and are implementing austerity measures while cutting back their "feed-in" tariffs. This is hurting the renewables industry as governments there have been subsidizing a rapid growth in solar and wind. Similarly, US renewable developers are struggling to raise funding as government incentives expire and bank lending dries up. Cheaper gas in the US is also providing stiff competition.

I don't want there to be any misunderstanding; we're bullish about renewables. Renewables continue to have long-term potential; technological improvements and falling costs are beginning to partially offset the barriers facing them. Prices for solar modules plummeted by nearly half last year alone, and about 75 percent over the past three years.

But there's been misleading hype about how quickly they could make an impact. As a result there have been a lot of disappointments. And the short-term downward pressure; political, technical and economic hurdles; and the massive global energy infrastructure which must be transformed means that renewables are still only a fraction of the total energy mix and only likely to gain market share in slow increments.

One of the consequences of lower US gas prices and downward pressure on renewables we're seeing is that when it comes to electricity generation, the economics of relatively clean natural gas are making a stronger case than coal, nuclear, and renewables.

Fourth, the global financial crisis is clearly having an impact on environmental legislation.

Issues such as the affordability of initiatives and investments, job creation, and the reality of renewables are exerting more pressure on the minds of austerity-minded governments. The result is a loss of urgency on global warming legislation which would have required a massive infusion of funds that hard-pressed countries can ill-afford.

For example, we only have to look at the disappointment of Copenhagen; the uncertain future of Kyoto; and the failure to implement the Bali Plan of Action to conclude that targets such as the IEA's 450 parts per million CO_2 scenario which called for the use of fossil fuels to peak before 2020 have become almost impossible to attain.

To sum up, our industry now faces downward pressure on demand; supply abundance; a slow-down in the deployment of renewables; and reduced momentum on climate change legislation.

It doesn't mean our industry is in bad shape or that prices are going to collapse, but that's a profoundly altered world energy landscape from the one we faced a decade, or even just a few years, ago.

Profound Change At Saudi Aramco

These sweeping new realities underscore the perennial truth about our industry that it is always in a state of flux; yesterday's forecasts are rarely tomorrow's reality; uncertainty is our constant companion. The clear lesson from history is that the companies best placed to weather the short-term storms and thrive are those most able to adapt and plan for the long-term, and never allow complacency to set in.

At Saudi Aramco, we feel good about resources; operational excellence; reliability; safety. But we also know there could be surprises out there: political, economic, technology. And Aramco has never stood still. That's why we are undergoing a profound, proactive, and strategic transformation.

It's a transformation which ignored the temptation to take a short-term, less risky approach by continuing to run a best-in-class operation; improve incrementally on the areas where improvements are required; and basically protect the great company we have. Instead, the philosophy underpinning what we call our Accelerated Transformation Program, or ATP, is that we must leverage our strengths and comparative advantages to exploit the full potential of our company against the backdrop of a challenging agenda. That agenda includes four legs:

1. Re-shaping our portfolio as we transition from an oil and gas company to a fully integrated and competitive world-leading energy and chemical enterprise;
2. Being a catalyst for the Kingdom's economic growth;
3. Capacity building by step change improvements in our technology and human resource capabilities;
4. Overhauling our corporate systems and processes to make us more performance-focused and agile in the future.

Transformation Into A World Leading Energy and Chemicals Enterprise

With the planned transition to a world-leading energy and chemicals enterprise, we are strengthening our existing businesses, and adding new ones to broaden and strengthen our portfolio.

Existing Businesses

Let me begin with our existing businesses. We know that oil and gas will remain central players on the world energy scene for the foreseeable future. At our Board meeting in Tokyo earlier this year, we had a presentation from our upstream engineers and scientists who were presenting our long-term production profile showing where we would be producing, literally in the next century.

We also know that preserving our spare oil production capacity is crucial to maintaining oil market stability because it plays a pivotal role in protecting the world's economic health. It's a responsibility we have faithfully and reliably discharged over several decades, despite its high cost to us; and will continue to do so.

So we are continuing to strengthen our oil business to meet the rising call on our oil production; in fact, we plan to invest $35 billion over the next five years in crude oil exploration and development alone to keep our oil production portfolio robust. We are also planning to increase our conventional and unconventional gas supplies by almost 250 percent over the coming couple of decades. And there are vast areas of Saudi Arabia which have still not been adequately assessed, which will be aggressively explored.

New Businesses

Meanwhile, we will aggressively expand our business portfolio by pursuing related integration across conventional and unconventional areas, and diversify and grow earnings along the way while adding greater value to our streams. So we are leveraging our strengths and comparative advantages across our business in several important ways.

To begin with, and in contrast with the prevailing global sentiment, we believe that large, integrated companies can build and sustain a turbocharged and profitable downstream business, yielding returns across the value chain. That's why we are moving ahead with a massive expansion of our global refining capacity, pushing the total worldwide capacity of refineries we own fully or through joint ventures up to some eight million barrels per day over the coming decade, the largest of any company in the world.

On the back of that expansion, we also believe there is huge potential for building a world-class petrochemicals business by integrating it with those world-scale refineries, as well as gas plants; NGL fractionation facilities; pipeline networks; hydrogen systems; storage and terminals. In doing so, between upstream, downstream, and chemicals, we will also reap other benefits from integration across the value chain, thereby maximizing profits from our oil; gas; NGL; and refined products, especially distressed hydrocarbon streams as inexpensive petrochemical feedstocks.

Then there's unconventional gas. Indications suggest that Saudi Arabia's unconventional gas potential could be as large as our conventional gas, with some estimates suggesting that the Kingdom could hold the world's fifth largest unconventional gas reserves. We are currently evaluating this potential.

Another distinct comparative advantage is solar energy. The Kingdom experiences roughly 3,000 hours of sunshine each year, emitting about 7,000 watts of energy per square meter, among the highest in the world. We have vast open spaces of desert, where large solar farms can be established on relatively cheap real estate. And we are blessed with deposits of quartz which can be used in the manufacture of polysilicon and photovoltaic cells.

Kingdom Economic Growth

The second part of our agenda, which is intrinsically linked with our ability to thrive, is being a catalyst for economic growth in Saudi Arabia as well as enabling a globally competitive and vibrant Saudi energy sector. We also need to create value addition and jobs for our young population which is a demographic challenge facing the Kingdom and many countries in the Middle East.

So we must help to develop the local energy support sector so that domestic suppliers have the opportunity to supply an increasing volume of our goods and services, including more high-value products. We must help to raise educational standards and develop a knowledge base for the Kingdom's future. And we must help to reduce the Kingdom's level of energy intensity and create a more energy efficient nation, while playing our part in diversifying the Saudi economy.

Good examples of this are the ones I just mentioned: chemicals, solar, and unconventional gas that are both good for our business and help expand and diversify the Kingdom's economy.

For instance, by growing and integrating chemicals with our world-scale refining operations, we plan to build a world-leading chemicals business. The materials produced by our chemical plants will help spawn new industries in Saudi Arabia. Many of these will be conversion industries located in industrial parks adjacent to our refining-petrochemicals manufacturing complexes, producing semi-finished and finished value added products. These downstream industries are likely to be much richer in value addition and jobs, while providing a platform for an emerging knowledge economy.

If we succeed with our strategy we will be spending at least $500 million each year on chemicals-related technology, and creating a very large company of around 20-30,000 employees with well-paid jobs. It also offers other Saudi companies a chance to be a part of a one trillion dollar global petrochemical industry by increasing Saudi industry's involvement to a level commensurate with our crude oil reserves.

Similarly, with solar, our vision is to help the Kingdom become the world's leading R&D hub and eventually a powerhouse across the full value chain of this energy sector. For starters, we've installed a 500-kilowatt solar farm on Farasan Island in the Red Sea, as part of our efforts to compare solar PV technologies and gain operating experience.

And when it comes to unconventional gas, if our quest is successful, there will be some major benefits for the Kingdom. We could replace liquid fuels with cleaner, more efficient natural gas for the Kingdom's electric power generation, providing more liquid hydrocarbons for export. Depending on the gas composition, it could provide additional feedstock for petrochemicals. Other economic benefits include localization, employment, and skill creation.

Capacity Building: Technology & Human Resources

But we are not only leveraging our sizeable capital and energy resources. The ATP is also designed to leverage the power of technology and the people in our company in support of our broadened portfolio and to succeed in an increasingly uncertain and challenging environment.

In technology, that means positioning Saudi Aramco as a leading force in creating energy technologies with the aim of meeting our unique requirements, consistent with our long-term business strategies. Our key challenges are to improve oil discovery and recovery; develop advanced fuel formulations, matched with future generations of engines; investigate cutting-edge chemical technologies; master carbon capture, focusing on mobile sources; maximizing the potential of nanotechnology and advanced materials and, as I just mentioned, advanced solar technologies.

Of course, we can't rely solely on developing technology solutions in-house, and are leveraging collaborations in many parts of the world. One of the most exciting developments is our recently-formed subsidiary, Saudi Aramco Energy Ventures, designed to invest in start-up technology companies which can generate greater value through innovative technologies in a wide range of areas from upstream and downstream oil and gas to energy efficiency and water.

But, for all that technology can offer, long-term human capital investment is just as critical. At Saudi Aramco, we saw that for ourselves just last month when we were the target of a malicious computer virus attack which tested our resilience. The reputation of Saudi Aramco as a reliable supplier of energy was maintained thanks to the resourcefulness, dedication, and ingenuity of our people. Customers were called; contracts were faxed; work-arounds were found.

In the final analysis, the petroleum business still comes down to people. That's why we are giving special attention to building our talent pipeline and unleashing the power of our increasingly youthful company, which by 2016 will see roughly 40 percent of our employees under the age of thirty. Our experience tells us that this generation is tech savvy, learns fast, and can deliver great performance if properly motivated. For that reason, we are training and developing them for the Company and, just as importantly, preparing the Company for them.

Corporate Systems & Processes

Part of that is fixing the plumbing and wiring – in other words, our own corporate systems and processes. As an industry, we're quite conservative in some ways, but this has to change. Among other things, this means changing our planning processes; learning new behaviors and skills; and busting bureaucracy – all of which we've been discussing at our Executive Management workshop this week.

Delivering the ATP goals, some of which I have briefly outlined, will sustain Saudi Aramco as a pre-eminent oil and gas exploration and production company. But it will also make us the world's largest refiner; one of the largest chemical companies; a leader in technology development; and we'll have a major position in power generation, including renewables. It's this potent combination, together with the talent of our people and the power of our cutting-edge technologies, which will help a great company to thrive even more in the new energy landscape.

Societal Expectations: Saudi Aramco's Role As A Global Corporation

There is one more reality we could add that affects IOCs and NOCs alike, which is rising societal expectations of global corporations.

When it comes to extractive industries in general and the petroleum industry in particular, many attractive resource-rich provinces around the world are located in developing nations. The people in these regions increasingly believe that while both NOCs and IOCs are benefiting from the exploitation of their natural endowments they are getting a raw deal while their natural resources are being depleted.

In addition, people's trust in business more generally has eroded around the world. This is clearly something we need to address collectively if we are to convince people that our priority is to provide reliable, affordable energy in a safe, secure, and environmentally responsible way, while investing in the well-being of the communities and countries in which we operate. In my view, simple compliance or box ticking is no longer adequate; our standards should be best-in-class. Let me elaborate.

We must link our long-term fortunes more deeply to the countries and regions where we do business. That could include onshore value addition; localization of goods and services; encouraging entrepreneurship; transferring technology and conducting real research in host nations; developing people; and supporting high quality education – much as we are doing in Saudi Arabia. Because a prosperous country from which we extract our resources or where our markets lie is clearly good for everyone's business.

None of this means that we will lose our commercial focus; on the contrary, we must be profitable enough to be able to meet societal expectations. But if we can work more closely together on these issues, our license to operate will be strengthened immeasurably and society will see our industry as a key enabler of prosperity, well-being, and aspiration.

Ladies and Gentlemen, we know our industry is changing profoundly, and we know we must respond proactively. We also know we must meet the challenge of rising societal expectations, wherever we operate. Change always creates anxiety and challenges, but also opportunities. Those of us who deal best with change will be ahead of the game. That's why I believe we should view the changing landscape as an opportunity to re-define ourselves, as we've done so many times before.

We should perhaps take our inspiration from the motto of this great college of St. Catherine's: Nova et Vetera – the new and the old. By leveraging our strength to tackle the new opportunities and fresh challenges of the changing world of energy, while drawing on timeless values and decades of hard-won experience, we can all be a thriving part of the energy world of tomorrow and meet our responsibilities."

Remarks at the World Energy Engineering Congress 2012

By Ahmad Al-Saadi, Vice President of Gas Operations, Saudi Aramco.

ATLANTA, 31 October 2012

"It is a genuine pleasure to speak at this exciting energy congress, and to be back in the United States. It is utterly humbling for me to speak on a program where the previous speakers of the day have included great world statesmen, President Jimmy Carter (who is also an energy engineer!) and General Colin Powell. I have taken part in conferences such as this on nearly every continent of the globe. Nowhere else have I seen such solidarity from leaders at the highest levels of politics and society with the professionals who are working on solutions to the problems of energy efficiency.

This is a tribute not only to the international leadership of our host organization, the Association of Energy Engineers, but also, I should say, to our host community, Atlanta. Since its beginnings in the 19th century, this great city has always been on the cutting edge of connectivity, from physical transportation on the great railroads and airlines to electronic media communications.

I admire Atlanta as a world-class center of innovation. Not only that, but as a man who lives and works in the desert of Saudi Arabia, I envy Atlanta for having the world's largest aquarium. Just imagine, the beautiful new Georgia Aquarium in this city holds more water than most of my country gets in a year of rainfall!

Now, any honor connected to my presence belongs to Saudi Aramco, the company I represent. On behalf of Saudi Aramco's management, again I want to express thanks for the Regional Energy Management Award presented yesterday.

Today I wish to offer you, first, a brief overview of Saudi Aramco's history and current business.

Second, I will describe the status of energy efficiency measures in Saudi Arabia.

Finally, I will present some details of the outstanding business and investment opportunities in Saudi Arabia. There are many exciting prospects for individuals and companies in the energy engineering profession and the many components of the energy and petrochemical services industries.

Saudi Aramco History

Saudi Aramco's history is deeply intertwined with the great energy industry of the United States. The original owner of the company, formed almost 80 years ago, was the predecessor of today's Chevron, operating with a concession from the Kingdom of Saudi Arabia. The company and the Kingdom became prosperous thanks to the perseverance of the firm's chief geologist, an American named Max Steineke. He insisted on drilling where others lacked the vision to explore. In honor of

"Because of economies of scale and supply chain efficiencies, as well as geographical advantages, we are investing in becoming one of the world's top refiners."

this visionary of the energy industry, this year Saudi Aramco endowed a professorship named for Max Steineke at his alma mater, Stanford University.

As the years went on, ownership in Aramco was shared by four large US oil companies until the Saudi government purchased the company in 1980. The American firms continued to manage the company during a transition period until 1988, when the current company, Saudi Aramco, was established under management by Saudi executives.

The United States continues to be vital for Saudi Aramco, supplying goods and services, as a partner in education, research and innovation, and as a valued oil customer.

Saudi Aramco Today

Today Saudi Aramco is a fully integrated, global petroleum and chemicals enterprise and a world leader in exploration, production, refining, distribution, shipping and marketing.

The Top Crude Oil Exporter

Nearly one in every seven barrels of oil that will be produced around the world today will come from Saudi Aramco. We are also the only producer with sizable spare production capacity, which plays a critical role in helping to stabilize markets and reduce volatility. Our maximum sustainable production capacity of 12 million barrels per day could supply about 15 percent of the world's demand for oil. Our proven crude oil reserves are the largest in the world.

Aiming for World Leadership in Refining and Chemicals

We have taken a strategic decision to expand our refining business even as some international oil companies are moving in different directions. Because of economies of scale and supply chain efficiencies, as well as geographical advantages, we are investing in becoming one of the world's top refiners. The Motiva refinery in Port Arthur, Texas, which we own jointly with Shell, is the largest refinery in the United States.

Pushing deeper downstream, Saudi Aramco is becoming a major player in petrochemicals. Our joint venture with Dow Chemical in Saudi Arabia, Sadara, will operate the world's largest integrated refining and petrochemical facility ever built at once. We have a sophisticated petrochemical joint venture with the Japanese company Sumitomo Chemicals already in operation in Saudi Arabia. Following development of the petrochemicals industry, Saudi Arabia will become a center for conversion industries for plastics and the manufacture of many industrial and consumer products derived from these joint ventures.

We also have major downstream assets and joint

> “... the government of the Kingdom, and Saudi Aramco, are working to make profound improvements in energy conservation.”

ventures in China, Korea, and Japan and our strategic intent is to expand chemicals investments and operations much further.

Our natural gas reserves are the fourth largest in the world; and I'll say more about our gas operations a bit later.

If any of you have not done business with Saudi Aramco or other enterprises in Saudi Arabia up until now, I hope my presentation will encourage you to look for opportunities to do so.

Catalyst for Social and Educational Development

Today, as always in the company's history, Saudi Aramco plays a major role in promoting education, health care, and other major elements of economic and social development of the Kingdom. Members of this audience at the World Energy Engineering Congress should have a particular interest in our latest efforts to promote critical skills for professional employment, as well as our strategy for promoting entrepreneurship in Saudi Arabia. As for employment opportunities, let me mention that Saudi Aramco has a booth just outside the luncheon area for job interviews and hiring purposes. We are recruiting engineers from all disciplines. Our interviewers will be at the booth in area every day through Friday, November 2nd.

A spirit of new thinking and "intrapreneurship" pervades Saudi Aramco as we pursue and ambitious multi-year effort called the Accelerated Transformation Program. This program calls for Saudi Aramco to leverage our strengths and comparative advantages to exploit the full potential of our company against the backdrop of a challenging agenda.

We will become a fully integrated and competitive world-leading energy and chemical enterprise and serve as a catalyst for further national economic growth, developing a competitive energy services industry in Saudi Arabia. We also are overhauling our corporate systems and processes to make us more performance-focused and agile in the future. Notably, we have a major initiative to improve our capital efficiency by 20 percent by the year 2015.

I mention all of these things because they are not solely of concern to Saudi Aramco's internal management. They relate to business opportunities for many of you and your firms taking part in this Congress. Implementing our corporate social responsibility programs and our business transformation will call for high quality services from contractors and other partners.

Energy Efficiency for Saudi Arabia

Saudi Arabia's energy efficiency lags behind the gains in efficiency in the United States, Western Europe, and many other industrialized societies. In fact, we have one of the world's highest energy intensity ratings. Therefore, the government of the Kingdom, and Saudi Aramco, are working to make profound improvements in energy conservation. Let me mention some of what we've already accomplished and some of our ongoing efforts:

> “Early indications by outside analysts suggest that Saudi Arabia may have the world’s fifth-largest reserves of unconventional gas.”

In 2011, we implemented 59 energy-saving initiatives and achieved energy savings of 10.08 thousand barrels of oil equivalent per day, which represents 3.5 percent of our total energy consumption for the year. This is enough to provide the annual energy supply of more than 2000 average Saudi Arabian homes.

Saudi Aramco continues to promote and develop energy conservation projects. The cogeneration strategy was implemented at four sites with power generation capabilities of 1250 MW and heat recovery to produce 4.8 Million pounds per hour of steam for use in gas processing processes. Future expansion includes additional generation capacity of 1,990 MW and 4.8 million pound per hour of steam. Reducing carbon dioxide (CO_2) emissions by more than 2.6 million metric tons annually, that would be equivalent to removing additional 1,000,000 cars from the roads.

Since the inception of our corporate Energy Management Program in 2000, our cumulative reduction in energy consumption has reached 122 MBDoe.

Efficiency of Natural Gas

Beyond the conservation efforts I have mentioned within our Gas Operations, conversion from oil to gas for power generation is inherently cleaner and more efficient. Saudi Arabia has made extraordinary progress since a generation or more ago, when associated gas in oil production usually was burned off in flaring. The Kingdom’s Master Gas System gave rise to a major supply of gas for turbine fuel and as feedstock for petrochemicals.

But Saudi Aramco’s quest for more gas discovery and production continues as a matter of urgency. Not only are we seeking major increases in conventional gas production, but we also are exploring for unconventional gas. Early indications by outside analysts suggest that Saudi Arabia may have the world’s fifth-largest reserves of unconventional gas. If we were to realize production of abundant unconventional gas, this would have very positive implications for our nation’s energy efficiency.

Saudi Arabia’s Strong Potential for Renewables

As the world’s largest petroleum company, we’re always being asked about the future of oil and the role of renewable energy. The world needs petroleum and we believe renewable energy will ultimately play an important role in helping to meet growing world energy demand responsibly.

For future generations, petroleum will remain a vital commodity, affecting almost every aspect of 21st century life. Forecasts to the year 2030 unanimously predict that oil will remain the main component of the global energy mix – even as global energy demand rises by 40 percent. That also means the world now has even more time for the gradual but meaningful development of renewables, and for them to overcome technical, economic, environmental and consumer acceptance obstacles.

While the progress of renewables will be gradual on a global scale, we are keen to develop them in Saudi Arabia. Every barrel of liquid we save from burning for domestic power generation is a barrel we can export for

> "Saudi Aramco is supporting the Kingdom's National Energy Strategy (NES) team to develop comprehensive approaches to energy efficiency challenges."

profit. Moreover, we have certain natural advantages in renewables.

Solar Energy from the Desert Sunshine

One clear advantage is solar energy. Saudi Arabia is one of the sunniest places on earth. With about 3,000 hours of sunshine each year, 7,000 watts of energy are emitted per square meter. In our tremendous open spaces of desert, we can establish large solar farms. We have huge deposits of quartz which can be used in the manufacture of polysilicon and photovoltaic cells.

Saudi Arabia aims to become a leading R&D hub and eventually a powerhouse across the full value chain of this energy sector. Toward this end, we've installed a 10 MW solar panel at a newly constructed "Al-Midra" office building in Saudi Aramco and a 500-kilowatt solar farm on Farasan Island in the Red Sea, as part of our efforts to compare solar PV technologies and gain operating experience. Saudi Aramco is also piloting a number of exciting solar powered projects in collaboration with the Saudi Electricity Company and Solar Frontier, our equity partner with Showa Shell of Japan.

National Energy Strategy

Saudi Aramco is supporting the Kingdom's National Energy Strategy (NES) team to develop comprehensive approaches to energy efficiency challenges. The NES team studies hydrocarbons supply, power supply, energy efficiency, and demand forecasting and management.

Saudi Aramco established new energy conservation guidelines for industrial facilities and non-industrial buildings within the Kingdom. The new energy efficiency guidelines are being applied by the Kingdom's fuel allocation committee to industries including cement, steel and petrochemicals. The guidelines establish minimum requirements for various aspects of all buildings, including heating, ventilation, air conditioning and lighting equipment. Full implementation of the non-industrial building guidelines is forecast to improve the energy efficiency of a typical building by 60 to 80 percent.

Our Imperative is Your Opportunity

I have tried to make one thing very clear today: Major gains in energy efficiency are imperative for Saudi Arabia.

Related to that, I believe the most important message you can take away today is this: Our imperative is your opportunity.

Specific Opportunities

Over the coming five years, Saudi Aramco's capital spending alone is budgeted for $125 billion dollars, and Saudi Government spending will be almost four times that, at $450 billion dollars. A significant amount of this spending will be toward enhancing energy efficiency.

Saudi Arabia is a welcoming environment for foreign direct investment. Enterprises that hire local talent

> "At Saudi Aramco, we aim to become as a leading force in creating energy technologies with the aim of meeting our unique requirements, consistent with our long-term business strategies."

and carry out local manufacturing enjoy attractive incentives and advantages. These include:

• A young, well educated population
• Plentiful energy supplies
• Abundant supplies of chemicals & minerals
• Ample land
• Geographic proximity to regional and global markets
• And a dynamic local and regional spending plan to nurture business growth in the region.

At Saudi Aramco, we aim to become as a leading force in creating energy technologies with the aim of meeting our unique requirements, consistent with our long-term business strategies.

Our key challenges are to improve oil discovery and recovery; develop advanced fuel formulations, matched with future generations of engines; investigate cutting-edge chemical technologies; master carbon capture, focusing on mobile sources; maximize the potential of nanotechnology and advanced materials and, as I have mentioned, promote energy efficiency.

Our New Business Development Team: At Your Service

Saudi Aramco has a robust New Business Development organization led by a Vice President and a talented, motivated team. This team is ready to advise and assist potential partners and investors about opportunities to do business not only with Saudi Aramco, but with any enterprise or government agency in the Kingdom. At this luncheon, we are providing each of you with our New Business Development brochure. I encourage you to read it carefully and to be in touch with our team in regard to any question where we may be of help. Our team is ready to help in many ways. These include helping potential investors navigate among our government agencies, to locate land for facilities, and to identify prospective local partners.

The Kingdom of Saudi Arabia is looking for business partners, entrepreneurs, and investors not only for goods and services to promote energy efficiency, but also across a very wide range of investment and development. The Kingdom offers abundant opportunities for individual energy engineers and firms of every size and scope related to your profession.

Ladies and gentlemen, again, it is a great honor to the 55,000 men and women of Saudi Aramco that you have asked me to speak to this distinguished gathering. I hope I have sparked your awareness and interest in Saudi Aramco and indeed the entire Saudi Arabian economy as a focus of opportunity for the excellent professionals and businesses represented here."

H_2S Early Notification System for Production Pipelines: A Pilot Test

By George J. Hirezi, SPE, Faisal T. Al-Khelaiwi, SPE, Mohammed N. Al-Khamis, SPE, Saudi Aramco.

This paper was prepared for presentation at the Abu Dhabi International Petroleum Exhibition & Conference held in Abu Dhabi, UAE, 11–14 November 2012.

Abstract
The produced fluid of an oil field located in the Eastern Province of Saudi Arabia contains relatively high levels of H_2S. A pilot test was conducted by Saudi Aramco to install a wireless gas detection system along an oil pipeline in this field. The pilot test objectives include:

- Determining the communication availability and reliability of the remote wireless sensors where extending hardwired and fiber optic networks proved impractical and expensive, and

- Evaluating the usefulness of this system for early notification of toxic gas releases or pipe leaks in and around critical geographical areas by alerting the console operator and via e-mail and Short Message Service (SMS).

The piloted system includes six wireless sensors separated at an equal distance along a 2 kilometer oil pipeline. The sensors communicate wirelessly with a gateway receiver located in a shelter at a producer site. The wireless gateway is integrated with an existing Supervisory Control and Data Acquisition (SCADA) system by connecting it serially to a Remote Terminal Unit (RTU). Accordingly, the sensors measurement and diagnostic data is monitored by the Operators at their console in the control room. The same data is also accessible to the engineers at their desktops for real time monitoring and long term archiving purposes via the OSI PI System.

The test results of the year-long pilot indicated that the gateway receiver demonstrated very high reliability and availability since it had no failures during the test period. However, initially some of the wireless sensors had experienced minor but recoverable communication errors.

This paper describes the details of this pilot test and discusses the difficulties encountered during the project's testing phase along with the actions taken to mitigate such problems and subsequently improve the overall reliability and availability of the wireless communication.

Introduction
An oil field located in the eastern region of Saudi Arabia near populated residential areas produces sour

oil from multiple reservoirs with H_2S content ranging from 6 to 16 mol%. This field is one of the first fields in Saudi Aramco that adopted the Intelligent Field Concept which calls for the instrumentation of the wellbores, wellheads and flow lines with the appropriate sensors and controls to enable real-time monitoring of the reservoir, wells and total field performance in addition to the provision of the ability to control the produced or injected fluid remotely. Nearly 40% of the producing wells are equipped with Permanent Downhole Monitoring Systems (PDHMS) and all the wellheads of producing and injection wells are equipped with pressure, temperature and H_2S sensors along with remotely actuated choke valves which provide real time data of the reservoir, wellbore and well surface performance in addition to the required control. Moreover, the producing and injection wells of this field are drilled from well-sites hosting 6 to10 wells per site. Each well-site is equipped with a Multiphase Flow Meter to provide semi-real-time measurement of the produced well fluid. H_2S sensors are also installed on the site fence in a 360° topology to provide full H_2S leak detection of the site. These sensors are connected to the Well and Site Emergency Shut-Down system and the SCADA to ensure that any hydrocarbon leak is detected and mitigated immediately.

The fluid flow lines running from the well sites to the Gas Oil Separation Plants are scraped regularly to eliminate any stagnation of fluid or solids that might induce corrosion and leaks of H_2S laden fluid. The flow lines are also externally coated to eliminate external corrosion wherever they are buried under the ground. All the required monitoring instrumentation is installed on the exposed sections of the lines and connected to the SCADA system.

However, a H_2S leak detection system is being considered for installation along the flow lines as a precautionary measure providing alerts to the console operators and engineers through real-time, continuous monitoring of any H_2S release through pin-hole leaks. An economic evaluation comparing the installation of hard wired to wireless detection system indicated that the latter is by far the better economical option.

Therefore a pilot test of a wireless H_2S detection system was conducted. The objective of this pilot is to test the functionality, reliability and availability of the H_2S wireless sensors and gateway technology for transmitting H_2S gas concentration measurements at the pipeline locations.

The intent is to utilize such wireless system along oil pipelines passing through or in the vicinity of residential and populated areas where gas release or oil spills can cause serious safety hazard situations. Subsequently, the system will provide early notification of any gas release allowing operators to respond in a timely manner.

Project Description

System Hardware:

Six complete standalone H_2S sensor units S-1 through S-6 (Figure 1) with solar array and integrated battery charger have been installed along the pipeline connecting the oil sites X-1, X-1A and X-3 (Figure 2). The sensors communicate H_2S measurements and

Figure 1. Complete Sensor Assembly.

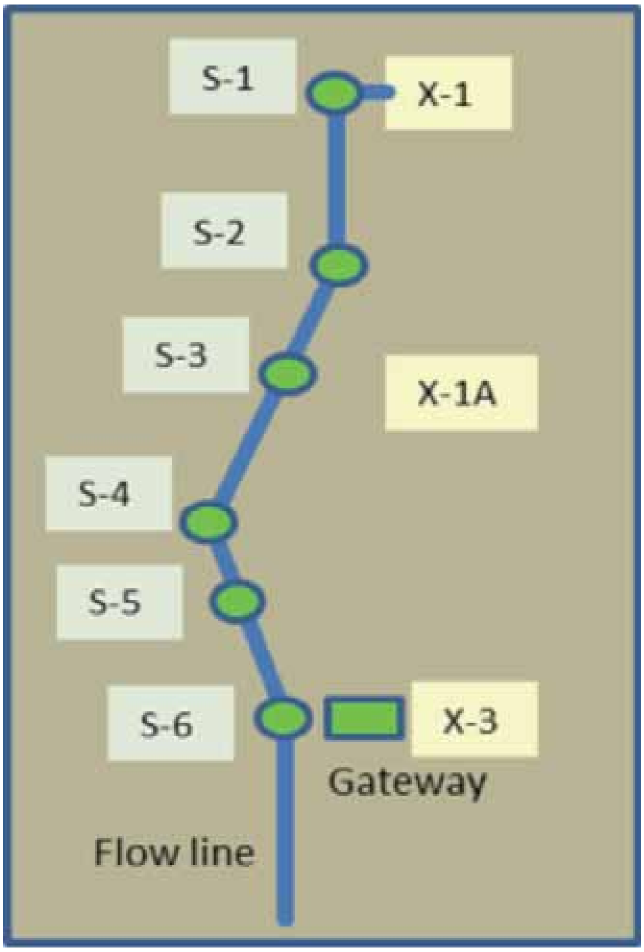


Figure 2. Approximate Sensors and Receiver Locations.

Figure 3. Wireless Gateway.

sensor statuses wirelessly to the receiver/gateway unit (Figure 3) which has been installed at X-3. The receiver/gateway communicates with the Remote Terminal Unit (RTU) at X-3 using RS-485 serial protocol and then to the SCADA and PI systems via the existing network.

Wireless Sensors: The sensors are installed in the proximity of the crude pipeline at approximately 40 feet away from the line. The sensors are arbitrarily placed between two producer sites X-1 and X-3; a distance of 2 km and at approximately 300 meters separation between the sensors. The unit is powered by a NiMH rechargeable battery to provide continuous power to the unit sensor and wireless communication electronics. The normal voltage output of the battery system is 14 volts, but the transmitter can still operate at a voltage as low as 7 volts. The sensor hardware specifications were inspected and crossed checked against applicable Saudi Aramco material specifications and two discrepancies were found and described below.

• The maximum sensor operating temperature falls short of Saudi Aramco's requirement. Yet, the sensors have been installed and operating under the direct sunlight without any failure.

• The tested sensor type is electrochemical. This is the most commonly used technology in the industry for H_2S sensing, but no longer accepted by Saudi Aramco. However, Saudi Aramco approves solid state Metal Oxide Semiconductor (MOS) type, which is now commercially available.

Wireless Receiver/Gateway: One wireless gateway was installed in the X-3 RTU Shelter. The gateway Monitor is configured to interface with the 6 H_2S sensors over wireless network running at 2.4 GHz. The unit displays sensor gas reading and status like sensor calibration, fault and battery voltage.

System Functionality

Wireless Sensors: The six H_2S sensors communicate wirelessly with the gateway receiver (H_2S Controller) over the 2.4 GHz frequency using IEEE 802.30 protocol. Due to the relatively longer distance (300 meters) between sensors 1 and 2 and the gateway, these sensors were equipped with high gain unidirectional antennas (Figure 4) allowing reliable communication between the sensors and the gateway located at the shelter. The remaining sensors were equipped with standard Omni antenna. The sensor H_2S measurement, sensor status, and the unit rechargeable battery voltage are transmitted wirelessly to the gateway. The sensor unit is active continuously with LCD always displaying H_2S gas level.

Gateway/Receiver: The Gateway collects the real-time H_2S concentration data from the sensors and makes it available on the local graphical LCD for monitoring purposes. The diagnostic information of the sensors are also transmitted and monitored at the gateway device. The gateway is interfaced with the existing SCADA system via the RTU using RS-485 communication link over MODBUS protocol. A signal booster/filter was installed on the link to eliminate any communication noise reaching the gateway and to prevent voltage disturbance that could damage the device.

System SCADA Integration

The wireless H_2S sensors and associated gateway are integrated with the existing SCADA system at the field through the RTU installed in X-3 shelter. Figure 5, describes the overall system architecture including the wireless H_2S equipment.

SCADA Configuration: The SCADA server database was updated to include the new H_2S measurement and status indications. In addition, the SCADA system is configured to provide the operators with "Warning" and "High" alarm indications on a custom display when sensor gas level measurements reach 10 ppm, and 20 ppm, respectively. This custom display is accessible to the Operator at his console in the Central Control Room (CCR). The custom display is also accessible to the shift superintendent at the SCADA console installed in the Disaster Control Center (DCC) room at the Administration Building.

Figure 4. Antenna.

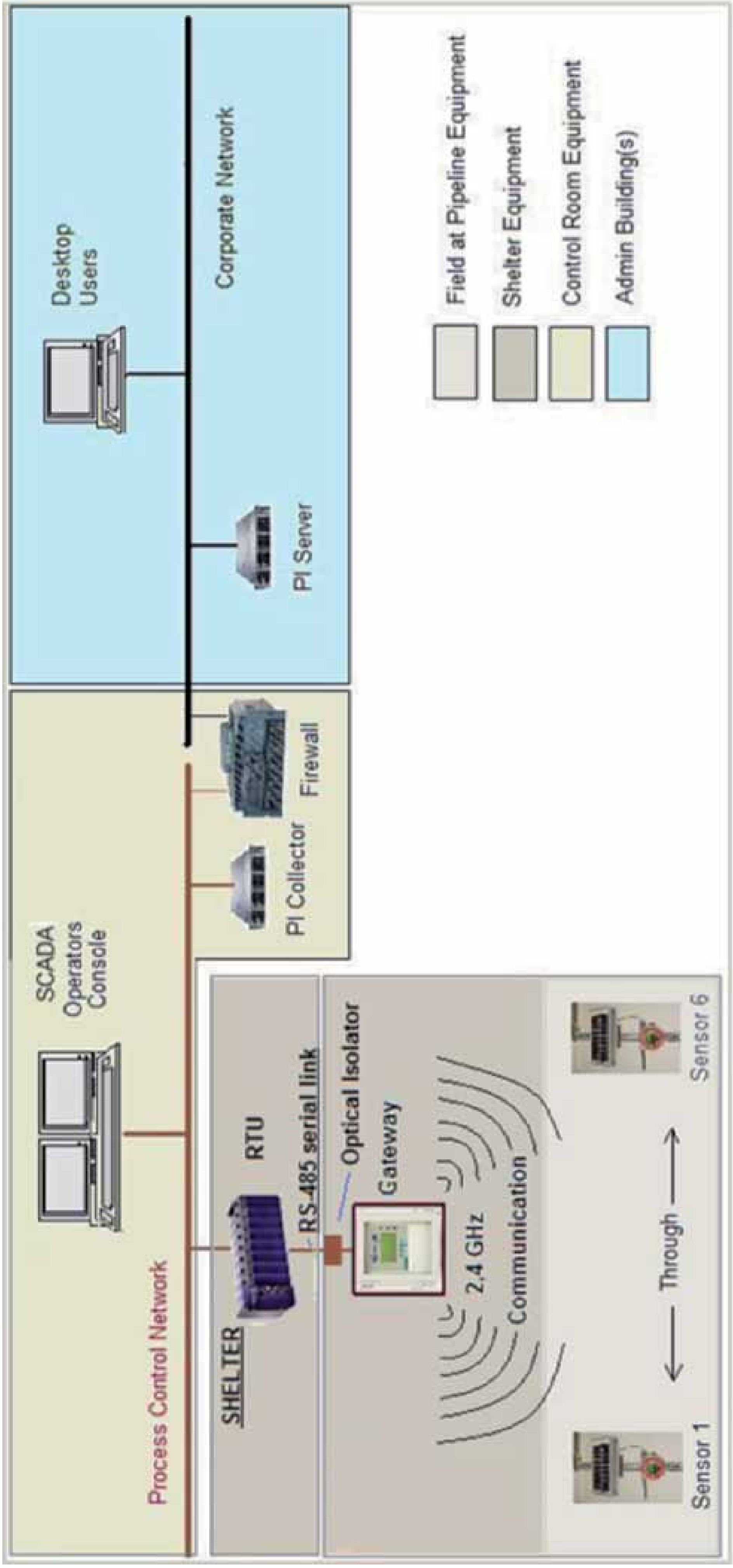


Figure 5. Wireless H_2S Early Notification System Architecture.

PI System Configuration: The PI system is configured to receive real-time H_2S measurements, diagnostic information of the sensor electronics, and the voltage measurement of the rechargeable battery at 10 seconds intervals from the SCADA system. The values of the PI tags are read from the SCADA server over an existing industry standard interface, namely OPC (Object Linking & Embedding for Process Control). These indications are archived on the PI server for future analysis of system performance. The data is also monitored by the production engineers at their desktops.

Short Message Services (SMS) and Email Notification: Standalone servers sitting on the corporate network were configured to send emails and SMS notification message to key operation, engineering, and management personnel.

Testing

The installation, configuration, and integration of the wireless system were completed in the 4th quarter of 2009 marking the commencement of the testing phase. First successful bump test was performed on October 19, 2009. However, the system testing was put on-hold pending evaluation and implementation of the requirements set in the guidelines released by the Communications and Information Technology Commission (CITC). In addition, the Receiver/Gateway was relocated from site X-2 (arbitrary location not shown in Figure 2) in compliance with the guidelines and avoiding any signal crossing over private properties or military installations. The relocation of the gateway was completed in February of 2010.

In February and May 2010, the 2nd and 3rd bump tests were performed and the data collected indicated unstable communication between the gateway and the RTU. Troubleshooting revealed that the existing serial link where the gateway was added not wired per the ISA guidelines. The serial link connecting the PDHMS and the newly added receiver were in a trunk and spur configuration whereas ISA guidelines recommend such link to be in a daisy chain configuration. The serial link was rewired properly and the communication between the receiver/gateway and the RTU was mitigated in the 3rd quarter of 2010. Furthermore, an optical isolator was installed at the receiver/gateway communication module to act as a signal filter/booster and surge protection.

Subsequently, the testing was resumed in August of 2010 where a partial bump test was performed. As a result, the data from 4 out of 6 sensors were received at the wireless gateway, SCADA, and PI systems, while the data received from sensors 1 and 2 data were not reliable as these two sensors are located relatively far away from the receiver gateway. Consequently, the existing sensors 1 and 2 Omni antennas were replaced early September 2010 with unidirectional antennas allowing more reliable communication from these two distant sensors. With this modification, the data received at the receiver/gateway, SCADA, and PI system were consistently available. All the bump test results are available in Appendix B.

Following the change, the system operation was monitored through continuous collection of the gas measurements and sensors diagnostic information. On January 26, 2011, the final bump test was performed, and the system testing was concluded on August 15, 2011.

After the conclusion of the testing phase, additional soft (simulated) bump tests we carried out to test the SMS and Email notification system.

Results

Twelve months of archived process and diagnostic data stored in the PI system between August 15, 2010 and August 15, 2011 was collected and analyzed. However, due to sensors 1 and 2 communication issues during the first month (M1) of testing that necessitated replacement of the antennas, the data for these two sensors were excluded from the performance calculations. Accordingly, the performance calculations depicted in Table 2 do not account for M1 data for the two sensors.

The main focus of testing the integrated system is the wireless communication. Therefore, the data was analyzed for three main performance indicators: Sensor Functionality, Wireless Availability and Wireless Reliability.

Functionality is defined as the system performance to deliver set of functions required to meet the objective of the system. In this trial testing, true system functionality could not be achieved without a Quantitative Risk Assessment (QRA) study to identify the quantities of the required sensors and associated spacing that would provide adequate gas detection coverage. As mentioned earlier, only 6 wireless sensors were sparsely distributed along the crude pipeline of 2 km long. However, sensors Functionality was verified by conducting periodic bump tests, in which 50 ppm

H_2S gas was safely injected into the sensors. This provided assurance that the sensors are still operating at different conditions throughout the testing phase. The sensor measurements were observed at the SCADA operator console as well as the engineers desktop. Wireless reliability is determined by calculating the "Mean Time Between Failures" (MTBF) in hours, while availability is the percentage of time when the system is operational. This availability is calculated by also determining the "Mean Time To Repair" (MTTR) which is the downtime in hours. The following is the formula used in determining the availability of the system individual components:

$$Availability = \frac{MTBF}{MTBF + MTTR}$$

The MTBF and Availability were calculated for the four individual system components; SCADA system, wireless controller, wireless sensors, and sensor solar power. In addition, the series MTBF and Availability of the four system components combined as one integrated system (series) was calculated using the formulas listed below:

Series Availability=A1 x A2 x A3 x…x An

$$Series\ MTBF = \frac{1}{\frac{1}{MTBF1} + \frac{1}{MTBF2} + \frac{1}{MTBF3} + .. + \frac{1}{MTBFn}}$$

Where:

A1 = SCADA Availability, A2 = Wireless Controller Availability, A3 = Series (S1, S2, …S6) Availability, A4= Battery Charger Avail, MTBF1 = SCADA, MTBF2 = Wireless Controller, MTBF3 = Series MTBF (S1, S2…. S6), MTBF4 = Battery Charger

The results of the individual components' reliability and availability are described in the following sections 5.1 through 5.3. Moreover, detailed and graphical representation of the calculated results for the reliability and availability of the individual components and the series (integrated system) are found in Appendix A.

SCADA System: The SCADA system failure information and availability are shown on Table 1. The results show 83.87% SCADA availability. This relatively moderate efficiency is attributed to the frequent failures of the SCADA hardware or/and communication between the SCADA servers and the RTU communicating over the Open Transport Network (OTN).

Wireless Gateway Controller: During the original installation, unstable serial communication between the wireless Controller and the Remote Terminal Unit (RTU) were observed. The communication problem was mitigated by installing an optical isolator (signal booster/filter). Subsequently, the communication between the controller and the RTU has been flawless. Also, no underlying controller hardware issue was observed. Therefore, the availability of the controller throughout the one year test period was 100%.

Wireless H_2S Sensors: Diagnostic information regarding each sensor is available on the Controller as a status byte (8 bits) where it is passed on to the PI system. The information is collected, archived and used to determine the healthiness state of the sensors, wireless communications, and solar power (battery). The following sections describe the test results of these components:

Sensor Wireless Communication: Communication reliability between the wireless sensor and the gateway is calculated slightly different from SCADA and the gateway.

During normal operation when no H_2S is present and the sensor is reading 0 H_2S, the data communication between the gateway and the sensor is generated once every 45 seconds (The communication rate changes automatically to < 5 seconds when there is H_2S). If communication between the gateway and the sensor fails 2 times consecutively, then the gateway will generate a No-Communication flag. This flag in turn generates a "NoComm Event" in the SCADA. Table 2 summarizes the sensors overall communi-

Table 1: One-Year SCADA System Failure and Availability Results

	ONE-YEAR OVERALL			
	No. Of Failures	MTBF	MTTR	Availability
SCADA	200	36.82	7.08	83.87%

Table 2: One-Year Overall Sensor Wireless Communication Failure & Availability Results.

	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6
No. of Failures	18	31	0	0	0	191
MTBF	18.53**	258.14**	N/F*	N/F*	N/F*	45.78
MTTR	0.005**	0.128**	0	0	0	0.173
Availability	99.97%	99.95%	100%	100%	100%	99.62%

**N/F – No Failure (i.e. MTBF is infinity hours)*
*** M1 Data between 8/16/2010 and 9/15/2010 was excluded from the performance calculations of sensors 1 & 2.*

Table 3: Sensor Function Testing Results.

Maximum Reading	S1	S2	S3	S 4	S 5	S 6
1st Test October 2009 (introduced 40ppm)	39	39	39	40	40	40
Sensor (%Error)	-1 (-3%)	-1 (-3%)	-1 (-3%)	0 (0%)	0 (0%)	0 (0%)
Last Test January 2011 (Introduced 50 ppm)	57	50	54	53	54	54
Sensor (%Error)	7 (14%)	0 (0%)	4 (8%)	3(6%)	4 (8%)	4 (8%)
Measurement Deviation over 15 months (%)	**+8%**	**+1%**	**+5%**	**+3%**	**+4%**	**+4%**

cation availability and reliability results over the 12 months.

The archived diagnostic data revealed none of the sensors experienced any hardware fault during the testing phase. However, the communication of sensors 1, 2 and 6 suffered instabilities as indicated in Table 2 above, but remain within acceptable availability levels. Appendix A shows detailed monthly breakdown of these sensors performance indicators.

Sensor Solar Power (Battery): The archived diagnostic data showed no fault had occurred on any of the solar power system components during the testing period. Therefore, the availability of the sensors solar batteries throughout the testing period was 100%.

Sensor Function Testing: The functionality of the sensors was observed by performing bump tests on each sensor by safely introducing a predetermined amount (40 or 50 ppm) of H_2S gas. A total of 5 bump tests were conducted during the trial test period. Table 3 summarizes the results of the first and last bump test showing the measurement deviation (%) at each test, and the net deviation over 15 months of service:

SMS and Email Notifications: Soft simulated bump tests that were carried out were successful and proved critical for immediate notification of gas releases not only for operations, but also key engineering and managerial personnel.

Conclusion and Recommendations

Conclusion

The main focus of this pilot testing was to determine suitability of wireless technology as a communication solution for an early gas release notification by determining the reliability and availability of the vendor provided wireless sensors, receiver gateway, and the wireless communication individually and as a wireless system integrated with the SCADA. Accordingly, the test results indicated that the gateway receiver demonstrated high reliability and availability as it experienced no failures during the test period. However, 3 of the wireless sensors experienced minor but recoverable self-healing communication errors resulting to an overall sensors wireless communication MTTR (error self-recovery) of 0.057 hours, and "Mean Time Between Failures (MTBF)" of 12.55 hours resulting to a calculated availability of 99.55% (see Appendix A). The SCADA system also experienced intermittent failures at a MTBF of 36.82 hours. Please note, SCADA problem mitigations are carried out manually by technician or engineers which took longer time to repair resulting to MTTR of 7.08 hours. Consequently, the SCADA system availability was compromised to a lower percentage of 83.87%. Subsequently, the overall integrated system (Wireless gateway, wireless sensors, and SCADA) communication reliability (series MTBF) and availability was determined to be 9.36 hours, and 83.48%, respectively. Therefore, the results show acceptable level of reliability and availability for the wireless system provided by the vendor, but the performance of the SCADA system needs improvement.

A review of the wireless Communication Protocol of the piloted system indicated that the current wireless communication protocol for the sensors is proprietary while Saudi Aramco long term direction is to adopt the ISA 100.11a protocol. Nonetheless, ISA 100.11a is currently available in the industry and can be integrated to any wired instrument. Moreover, as per the sensor specification, the maximum operating temperature is +50°C which does not meet the current instrumentation standards of Saudi Aramco.

Recommendations

• Quantitative Risk Assessment (QRA) study should be performed prior to full deployment of such systems to identify the critical areas and quantities of the required sensors and associated spacing that would provide adequate gas detection coverage.

• To ensure compatibility among various vendors, and long term maintainability and support, it is recommended to use ISA100.11a compatible wireless instruments in the full deployment of such system.

• High-level system notification of gas release beyond the control room is recommended. This can be accomplished by implementing Short Messaging Services (SMS) to notify key personnel on their mobile phones.

Acknowledgments

The authors would like to thank all team members from various respected Saudi Aramco departments who effectively participated in this trial test. The appreciation is extended to Saudi Aramco management for allowing publishing this paper and finally to PEMTECH, Inc. for providing and installing the wireless equipment and offering their unconditional technical support during the testing phase.

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5. To assure compatibility among various vendors, and long term maintainability and support, it is recommended to use ISA100.11a compatible wireless instruments in the full deployment of such systems.

Appendix A: Reliability, Availability Performance Indicators

A.1 Reliability

A.1.1 Detailed MTBF (Hours) results of all individual, system, and integrated components.

MTBF (in Hours)	SCADA	Controller	S1	S2	S3	S4	S5	S6
M1	7.49	N/F	1.35*	1.26*	N/F	N/F	N/F	25.22
M2	86.24	N/F	54.92	41.76	N/F	N/F	N/F	34.06
M3	42.66	N/F	243.44	73.37	N/F	N/F	N/F	104.54
M4	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F
M5	367.51	N/F	370.25	N/F	N/F	N/F	N/F	N/F
M6	56.42	N/F	N/F	N/F	N/F	N/F	N/F	733.27
M7	162.55	N/F	N/F	N/F	N/F	N/F	N/F	N/F
M8	41.24	N/F	N/F	633.94	N/F	N/F	N/F	70.35
M9	18.36	N/F	N/F	N/F	N/F	N/F	N/F	54.43
M10	34.13	N/F	N/F	N/F	N/F	N/F	N/F	33.42
M11	66.78	N/F	N/F	N/F	N/F	N/F	N/F	16.36
M12	27.44	N/F	N/F	245.66	N/F	N/F	N/F	13.64
Individual Component	36.82	N/F	18.53	258.14	N/F	N/F	N/F	45.78
Individual System	36.82	N/F	12.55					
Overall Integrated System	9.36							

** M1 data was excluded from the performance calculations of sensors 1 & 2*

A.1.2 Detailed MTTR results (Hrs) of all individual, system, and integrated components.

MTTR (in Hours)	SCADA	Controller	S1	S2	S3	S4	S5	S6
M1	1.46	N/F	0.89*	1.26*	N/F	N/F	N/F	0.14
M2	3.25	N/F	0.11	0.13	N/F	N/F	N/F	0.12
M3	6.07	N/F	0.19	0.11	N/F	N/F	N/F	0.16
M4	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F
M5	0.11	N/F	0.10	N/F	N/F	N/F	N/F	N/F
M6	25.70	N/F	N/F	N/F	N/F	N/F	N/F	0.32
M7	40.64	N/F	N/F	N/F	N/F	N/F	N/F	N/F
M8	2.95	N/F	N/F	0.05	N/F	N/F	N/F	0.09
M9	1.67	N/F	N/F	N/F	N/F	N/F	N/F	0.03
M10	2.01	N/F	N/F	N/F	N/F	N/F	N/F	0.16
M11	6.68	N/F	N/F	N/F	N/F	N/F	N/F	0.14
M12	1.10	N/F	N/F	0.21	N/F	N/F	N/F	0.27
Individual Component	7.08	N/F	0.01	0.13	N/F	N/F	N/F	0.17
Individual System	7.08	N/F	0.057					
Overall Integrated System	1.852							

** M1 data was excluded from the performance calculations of sensors 1 & 2*

A.1.3 Detailed results for Availability of all individual, system, and integrated components.

Availability (%)	SCADA	Controller	S1	S2	S3	S4	S5	S6
M1	83.68%	100.00%	60.28%	50.05%	100.00%	100.00%	100.00%	99.44%
M2	96.37%	100.00%	99.81%	99.69%	100.00%	100.00%	100.00%	99.65%
M3	87.54%	100.00%	99.92%	99.85%	100.00%	100.00%	100.00%	99.84%
M4	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
M5	99.97%	100.00%	99.97%	100.00%	100.00%	100.00%	100.00%	100.00%
M6	68.70%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	99.96%
M7	80.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
M8	93.33%	100.00%	100.00%	99.99%	100.00%	100.00%	100.00%	99.87%
M9	91.67%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	99.95%
M10	94.44%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	99.51%
M11	90.91%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	99.14%
M12	96.15%	100.00%	100.00%	99.91%	100.00%	100.00%	100.00%	98.08%
Individual Component	83.87%	100.00%	99.97%	99.95%	100.00%	100.00%	100.00%	99.62%
Individual System	**83.87%**	**100.00%**	**99.55%**					
Overall Integrated System	83.48%							

Appendix B: Bump Test Results

B.1 October 19, 2009 Bump Test

Full Scale Range	100 ppm	**Gas Concentration**	40 ppm H_2S / Air
Test Date	October 19, 2009	**Test Gas Tolerance**	(± 5%)

Response to Test Gas	Ideal As per ISA 92.0.01	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6
Response time for 10 ppm	15 seconds	10-12	10-12	10-12	10-12	10-12	10-12
Response time for 25 ppm	30 seconds	~30	~30	~30	~30	~30	~30
Response time for 45 ppm	2 ½ Minutes	2	< 2	2.1	< 2	< 2	< 2
Max H_2S Readings indicated after 2 ½ minutes		39/40	39/40	39/40	40	40	40
Recovery time, down to 25 ppm	45 seconds	< 40	< 40	< 40	< 40	< 40	< 40
Recovery time, down to 5 ppm	2 – 3 minutes	< 2 min	< 2 min	< 2 min	< 2	< 2	< 2

B.2 February 20, 2010 Bump Test

Full Scale Range	100 ppm	**Gas Concentration**	50 ppm H_2S / Air
Test Date	February 20, 2010	**Test Gas Tolerance**	(± 5%)

Response to Test Gas	Ideal As per ISA 92.0.01	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6
Response time for 10 ppm	15 seconds	N/A	N/A	N/A	N/A	N/A	N/A
Response time for 25 ppm	30 seconds	N/A	N/A	N/A	N/A	N/A	N/A
Response time for 45 ppm	2 ½ Minutes	< 2	< 2	< 2	< 2	< 2	< 2
Max H_2S Readings indicated after 2 ½ minutes		50	50	50	50	50	50
Recovery time, down to 25 ppm	45 seconds	N/A	N/A	N/A	N/A	N/A	N/A
Recovery time, down to 5 ppm	2 – 3 minutes	~ 2 min	~ 2 min	~2 min	~2	~2	~2

B.3 May 18, 2010 Bump Test

Full Scale Range	100 ppm	**Gas Concentration**	40 ppm H_2S / Air
Test Date	May 18, 2010	**Test Gas Tolerance**	(± 5%)
Note: Last calibration performed prior to bump test was on Feb 20, 2010.			

Response to Test Gas	Ideal As per ISA 92.0.01	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6
Response time for 10 ppm	15 seconds	~15	~15	~17	~15	~15	~15
Response time for 25 ppm	30 seconds	~35	~35	~35	~30	~35	~30
Response time for 45 ppm	2 ½ Minutes	< 2	< 2	< 2	< 2	< 2	< 2
Max H_2S Readings indicated after 2 ½ minutes		48	49	48	48	47	49
Recovery time, down to 25 ppm	45 seconds	N/A	N/A	N/A	N/A	N/A	N/A
Recovery time, down to 5 ppm	2 – 3 minutes	< 40*	< 40*	< 40*	< 40*	< 40*	< 40*

*Not in line with previous test

B.4 January 23, 2011 Bump Test

Full Scale Range	100 ppm	**Gas Concentration**	25 ppm H_2S / Air
Test Date	January 23, 2011	**Test Gas Tolerance**	(± 5%)
Note: Last calibration performed prior to bump test was on May 18, 2010 (8 months ago)			

Response to Test Gas	Ideal As per ISA 92.0.01	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6
Response time for 10 ppm	15 seconds	~18	~17	~17	~17	~20	~17
Response time for 25 ppm	30 seconds	< 2	< 2	< 2	< 2	< 2	< 2
Response time for 45 ppm	2 ½ Minutes	N/A	N/A	N/A	N/A	N/A	N/A
Max H_2S Readings indicated after 2 ½ minutes		29	25	28	29	28	29
Recovery time, down to 25 ppm	45 seconds	N/A	N/A	N/A	N/A	N/A	N/A
Recovery time, down to 5 ppm	2 – 3 minutes	< 40*	< 40*	< 40*	< 40*	< 40*	< 40*

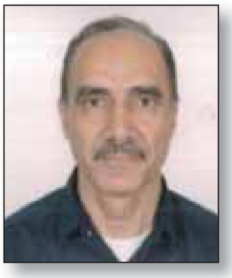
B.5 January 26, 2010 Bump Test

Full Scale Range	100 ppm	**Gas Concentration**	40 ppm H_2S / Air
Test Date	January 26, 2011	**Test Gas Tolerance**	(± 5%)

Response to Test Gas	Ideal As per ISA 92.0.01	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6
Response time for 10 ppm	15 seconds	~18	~17	~17	~17	~20	~17
Response time for 25 ppm	30 seconds	< 35	< 35	< 35	< 35	< 35	< 35
Response time for 45 ppm	2 ½ Minutes	<2	<2	<2	<2	<2	<2
Max H_2S Readings indicated after 2 ½ minutes		57	50	54	53	54	54
Recovery time, down to 25 ppm	45 seconds	N/A	N/A	N/A	N/A	N/A	N/A
Recovery time, down to 5 ppm	2 – 3 minutes	< 40*	< 40*	< 40*	< 40*	< 40*	< 40*

*Not in line with previous test

Biographies



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Real-Time Integrated Petrophysics: Geosteering in Challenging Geology and Fluid Systems

By Majed F. Kanfar.

Abstract

Since the advent of horizontal wells, the oil and gas industry has come a long way to ensure optimal drilling and well placement practices. The proper placement of these wells has meant that measurement while drilling (MWD) and logging while drilling and (LWD), have come to play a primary role in geosteering, placement and evaluation of highly deviated or horizontal wells.

This article presents a case study from a complex carbonate reservoir that has a low permeability zone in the middle of the reservoir and rimmed by a tar mat, which complicate the optimal placement of the horizontal producers and injectors. Conventional triple-combo logs lack the critical data to geosteer in this multifactorial environment. A comprehensive logging program was developed to integrate additional petrophysical data, such as formation pressure while drilling (FPWD), cuttings analysis, nuclear magnetic resonance while drilling (NMR-WD), and neural network processing.

Formation pressure while drilling is used in real-time to detect penetrated low mobililty/low permeability zones. Pressure buildup and drawdown measurements along with fluid mobility are used to modify the well trajectory. NMR while drilling is applied for placement of power water injection wells to detect zones bearing heavy immobile oil where the ability to inject is unlikely. Algorithms were developed to estimate the in-situ oil viscosity. Moreover, neural network models that in- corporate legacy well log and core data were used to predict lithofacies and rock permeability in real-time.

The workflow developed for this study demonstrates the necessity of additional petrophysical data and vigilance for real-time solutions to geosteer extended reach horizontal wells in heterogeneous geological systems.

Introduction

Conventional triple-combo logging while drilling (LWD) logs (neutron, density and resistivity) are usually sufficient in carbonate reservoirs in the Middle East to successfully geosteer a well to the target of interest and maintain it in the zone of interest. This is typically achieved by steering toward good porosity and satu- ration, using resistivity zones. The reservoir for this case study contains two flow barriers: a Low Permeability

Zone (LPZ), which acts as a flow inhibitor in the middle of the reservoir, and a tar mat at the periphery of the field that isolates the reservoir from the aquifer. Both of these barriers cannot be detected with conventional LWD logs.

The existence of these flow barriers in this reservoir poses a strong challenge for the geosteering team. The LPZ can only be accurately distinguished through measuring the rock mobility, which is not achievable with triple-combo log data. Moreover, the LWD triple-combo logs' responses to the tar mat are not unique when compared to zones bearing light oil. Additional prop- erties, such as hydrocarbon fluid viscosity or API gravity, are needed to identify heavy oil sections. Therefore, estimating in-situ properties, such as rock permeability and oil viscosity, are invaluable when drilling in this type of environment.

Advanced logging tools, such as formation pressure while drilling (FPWD) and nuclear magnetic resonance while drilling (NMR-WD), are often considered high-end suites, and are not routinely utilized in the evaluation of development wells. FPWD can be utilized to estimate formation mobility using pressure-time buildup and drawdown data. Advanced NMR analysis is applied to calculate in-situ oil viscosity, using in-house developed algorithms to identify the tar mat. Pyrolitic analysis is performed on drill cuttings to estimate oil, tar, and pyrobitumen volumes in the samples.

In addition to direct mobility measurements from FPWD, neural network models have been developed using legacy well logs and core data to estimate litho-facies and rock permeability, which are capable of being applied in real-time. Data propagated from the neural network models are crucial to identify zones with the desired geologic and petrophysical properties.

Geology

The field in this case study produces from a hetero-geneous limestone reservoir. This formation can be divided into three main sections based on its geology and petrophysical properties. The top portion of the reservoir, Zone A, is the main production target and is characterized by a cross-bedded oolitic grainstone, which has high porosity and high permeability. This is underlain by a mud-lean packstone, which has high porosity and low permeability due to its different depositional and diagenetic history. This interval acts as a flow baffle and is known as the LPZ. The LPZ has good porosity, very similar to Zone A. This poses a challenge for geosteering horizontal producers and injectors since the only way to positively distinguish between the two zones is through formation pressure and mobility measurements[1]. The lower portion of the reservoir, Zone B, is a production secondary target. It

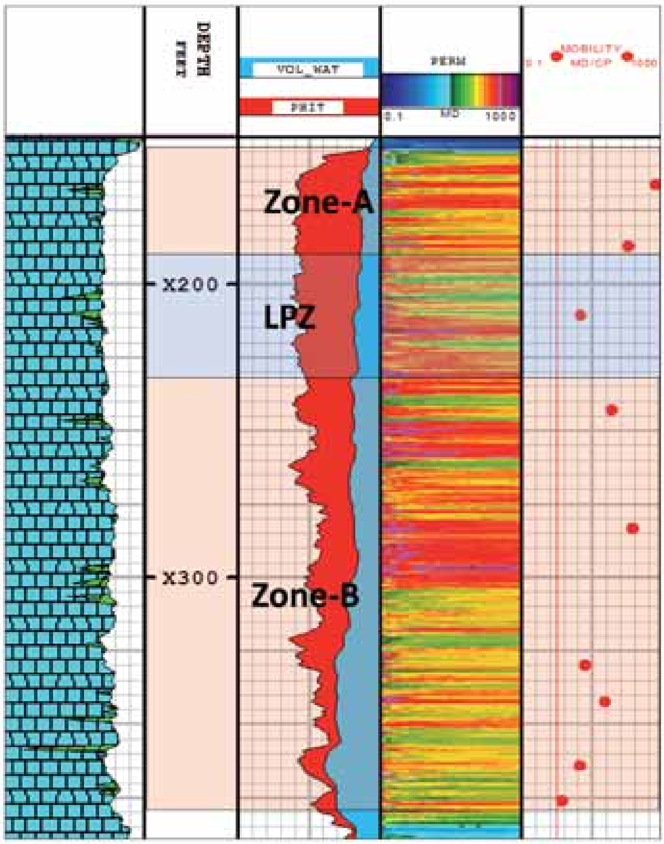

Fig. 1. Type log showing lithology and main reservoir zones. LPZ is validated by low mobility obtained from FPWD.

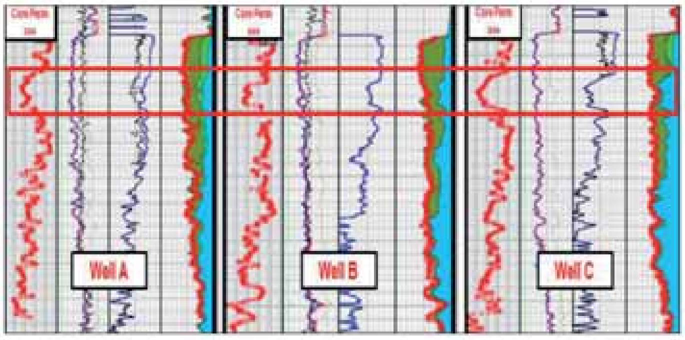

Fig. 2. East-West cross section showing permeability estimation from routine core analysis illustrating the lateral continuity of the LPZ.

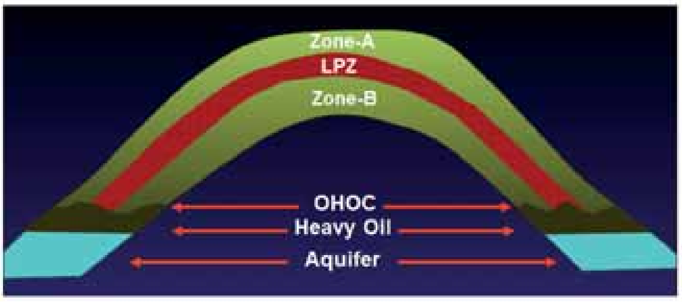

Fig. 3. Fluid distribution in the field structure. The heavy oil layer (tar mat) acts as a flow barrier between the reservoir and the aquifer.

is the most heterogeneous of the three zones characterized by bioturbated skeletal and pelloidal packstone. The porosity and permeability varies depending on the type of depositional facies. Figure 1 shows a typical petrophysical analysis for the overall reservoir.

A stratigraphic cross section across the reservoir, Fig. 2, shows the presence and lateral continuity of the LPZ across the field. Track 1 in the figure presents the core permeability showing the significant lower permeability in the zone in comparison to the permeability in Zones A and B. Prudent planning and thorough under- standing of the petrophysics is therefore needed to ensure a successful well placement and to prevent placement of the well in the LPZ.

Fluid Distribution

The reservoir of interest, in addition to the geological challenges, has a tar mat that is at the periphery of the field that acts as a barrier separating the reservoir from the aquifer. This necessitates the need to place injectors above the tar mat to maintain pressure support and to sweep the reservoir. Figure 3 shows a conceptual fluid distribution within the reservoir where there is a transition from light oil to heavier hydrocarbon as the reservoir deepens. Toward the base of the fluid there is an Oil-Heavy Oil-Contact (OHOC). Below the OHOC, the oil is significantly much more viscous than above the OHOC, which defines the top of the peripheral tar mat. The identification of the tar zone in injection wells is crucial to ensure proper injectivity.

Field Development Plan

The reservoir rock and fluid distribution make the development of this reservoir complex. Zones A and B are separated by the LPZ; therefore, a dedicated producer and injector are needed for efficient production in each zone. Well completions are done using 6⅛" open hole horizontal laterals.

Producers

For this field, horizontal producers and injectors are utilized to provide maximum reservoir contact. Producers in Zone A are placed at the top of Zone A. Similarly, producers in Zone B are placed between at the top of Zone B just below the LPZ. Identifying the LPZ is necessary in the placement of the Zone B producers, the challenge being that its porosity is very similar to the layers above and below it. Triple-combo type logs offer little assistance to positively identify a permeability change with a constant porosity. The placement of the producers in the heavy oil is unlikely, as the presence of heavy oil is not an issue in crestal regions of the field.

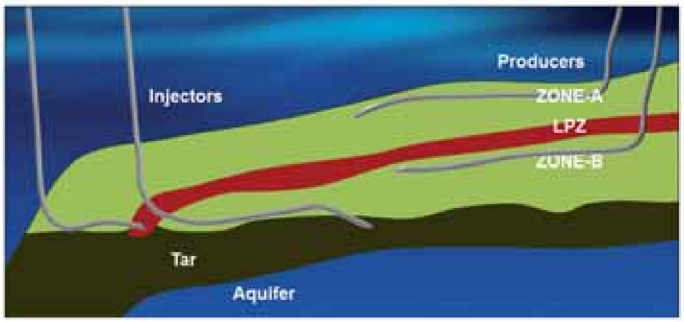

Fig. 4. Illustration of field development plan and well placement technique used for producers and injectors.

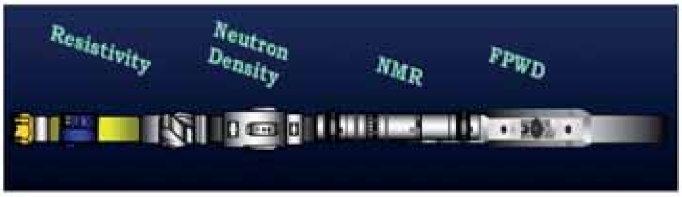

Fig. 5. LWD tool string used for horizontal injector well placement.

Injectors

Injectors are drilled on the periphery of the reservoir structure to ensure homogeneous bottom-up sweep and maintain reservoir pressure due to production. Injectivity tests performed show that the water aquifer is virtually sealed off from the hydrocarbon reservoir. Peripheral water injection into the water leg, to ensure a uniform bottom-up sweep, cannot be implemented due to the existence of the tar mat. The field development/drilling plan implemented addresses this challenge. There are two injection plans; each of which is dedicated to its respective production zone, Zones A or B. For Zone A, injectors are placed as low as possible in the oil column, just above the tar mat or the LPZ, to maximize oil recovery. Similarly, injectors for Zone B are drilled above the tar mat, but below the LPZ.

The real-time identification of tar is the major challenge in the geosteering of the injector wells for this project. Special logging tools and petrophysical analysis are required to delineate these zones. Figure 4 shows the development plan for the placement of the wells. On occasion, the toe section for injectors will be turned down into the LPZ or tar mat to map their respective tops and facilitate the planning of future wells.

Petrophysical Analysis

The conventional LWD triple-combo logs, neutron-density porosity, and resistivity do not provide sufficient data to properly evaluate and ensure a successful well placement for this project. An advanced logging program is used to successfully geosteer wells in this complex reservoir. Figure 5 shows the tool string used; in addition to the triple-combo, FPWD and slim NMR tools are added.

Neutron and density measurements are used to calculate the porosity and identify the formation lithology. Formation resistivity acquired from the resistivity tool is used to estimate the water saturation.

Detecting the LPZ is achieved through real-time mobility from the FPWD pressure time measurements. Supercharged pressures greater than the expected reservoir pressures are prevalent in low mobility environments and also contribute to the LPZ identification.

It is also notable that many of the pressure tests taken in this section were not successful due to “no seals” or “lost seals.” Low mobility formations take longer to form mud cake buildup that is crucial for sealing the FPWD packer and the formation from the borehole.

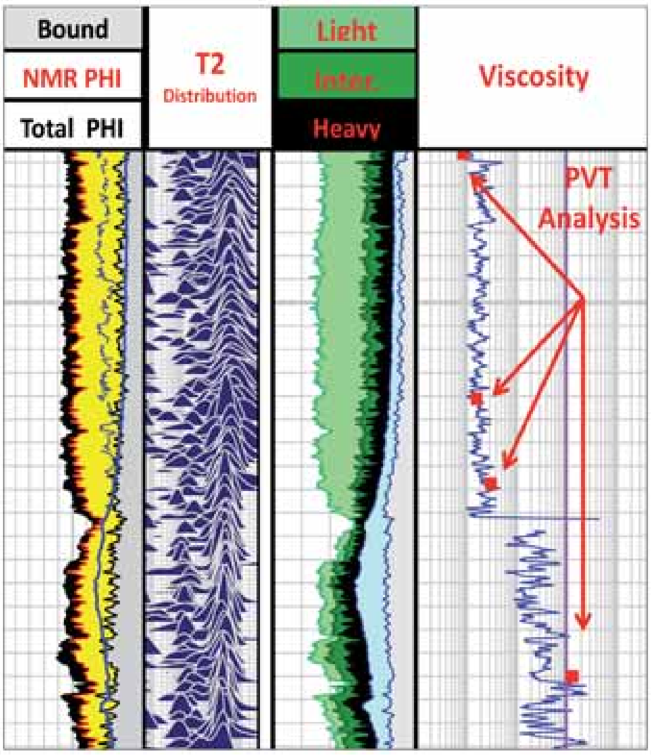

Fig. 6. Advanced NMR analysis. Track 1 shows porosity and bound fluid volumes from NMR with total porosity from neutron-density. NMR porosity deficit is explained by the presence of heavier oil, which results in a loss of the total NMR signal. Track 3 shows the oil components. Track 4 shows a comparison between the calculated NMR viscosity and viscosities from reservoir condition lab measurements.

Based on field experience, having consecutive "no seals" can be indicative in itself of the LPZ. Moreover, the neutron-density porosity tool is strategically placed closer to the drilling bit than the FPWD tool to prevent taking "blind" pressure tests before quantifying the porosity, Fig. 5.

Similar to the LPZ, when drilling in the tar mat, low mobility and supercharged pressures are also observed. This could lead to confusing the tar mat with the LPZ. Additional information is needed, such as fluid viscosity to positively identify the tar mat.

NMR-WD tools are used to identify movable and bound fluid volumes. In this project, NMR is used as the primary means to identify tar bearing intervals and quantify the fluid viscosity[2]. By integrating triple-combo data with NMR porosity and bound fluid volume data the in-situ oil viscosity, it can be determined using in-house developed algorithms. These algorithms determine the downhole hydrocarbon fluid viscosity. The results are calibrated to reservoir condition viscosity measurements done in the lab, Fig. 6. A comparison between NMR porosity and total porosity from neutron-density logs shows a discrepancy between the two porosity measurements. The deficit in NMR porosity can be explained by the loss of signal from the NMR tool due to the heavier oil.

Real-Time Formation Drill Cuttings Analysis

The drilling and placement of the horizontal injection wells poses the biggest challenge in this field development project. Tar bearing zones are identified using NMR and FPWD; however, pyrolytic analysis of the formation drill cuttings is run in parallel. The Pyrolytic Oil- Productivity Index (POPI)[3] is performed on drill cuttings to identify fluid properties, such as API gravity and bulk composition (i.e., black oil, tar, and pyrobitumen). Injectivity is estimated based on volume of tar and pyrobitumen volumes. Figure 7 shows a typical output for pyrolitic analysis showing the percentage of contamination, oil, tar and pyrobitumen.

Neural Network Algorithm

Porosity permeability cross-plots are conventionally used to model permeability by developing a regression through the data. This technique is applicable in relatively homogeneous formations and not always

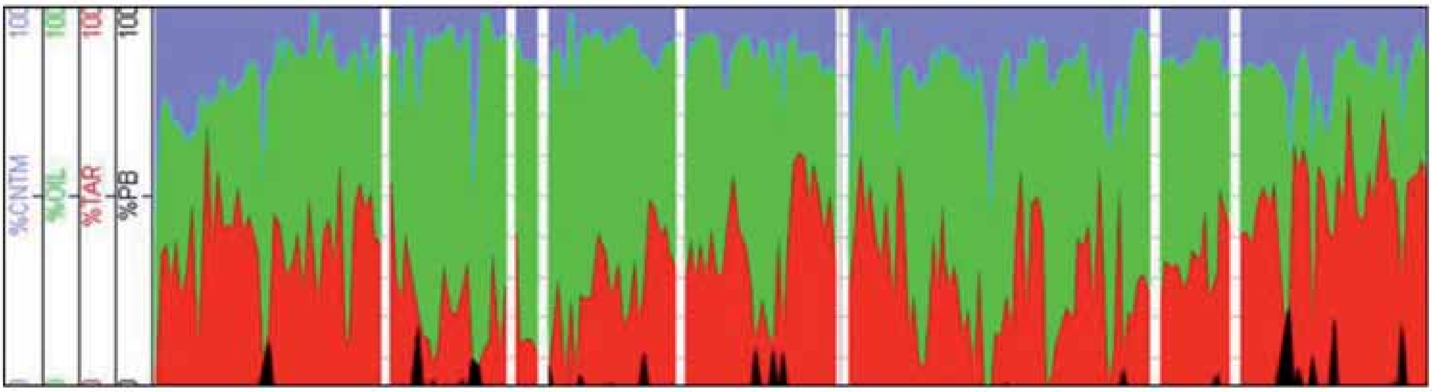

Fig. 7. POPI mud log analysis showing contamination, oil, tar, and pyrobitumen volumes.

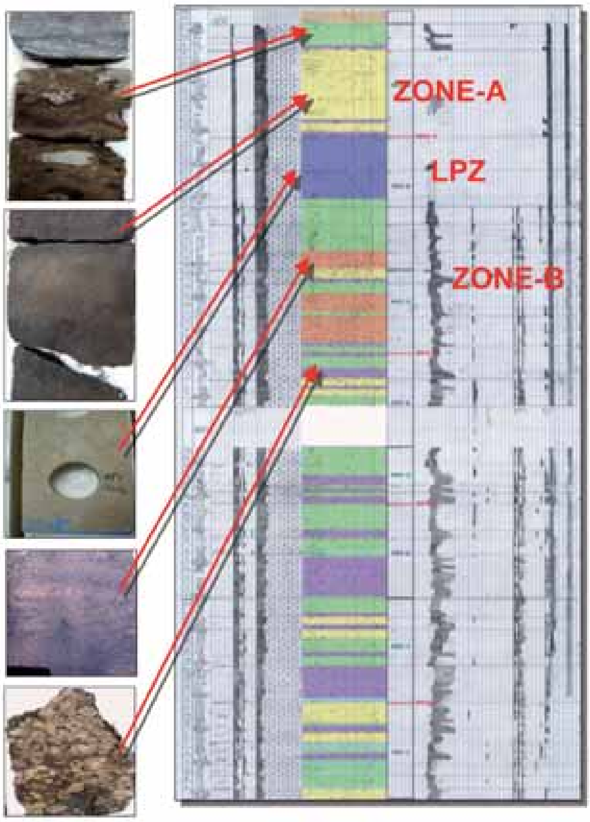

Fig. 8. Example core description used to develop permeability and facies prediction. Note how heterogeneous Zone B is.

applicable to carbonate reservoirs. This methodology does not capture the "highways" and "barrier" effects in complex pore systems encountered in this carbonate reservoir. In-house developed algorithms utilize the log data, permeability data, core descriptions (facies, hydraulic flow units) to determine the geologic facies and permeability[4]. Facies variations for a well are shown in Fig. 8. The details of this work are beyond the scope of this article. Figure 9 shows a comparison of the developed model to the core description and lab permeability measurements.

Case Study Example

It is standard to drill dedicated injection wells for each of the reservoir zones; Zones A and B. For this example, a well was drilled to be a comingled injector for both zones in an attempt to optimize the field development cost and minimize the drilling footprint. The logging tools utilized in drilling this well are shown in Fig. 5. This well extends more than 18,000 ft in measured depth and the total cost of drilling such wells is high. The cost of the wells and the complexity of the reservoir and fluids make using specialized logging

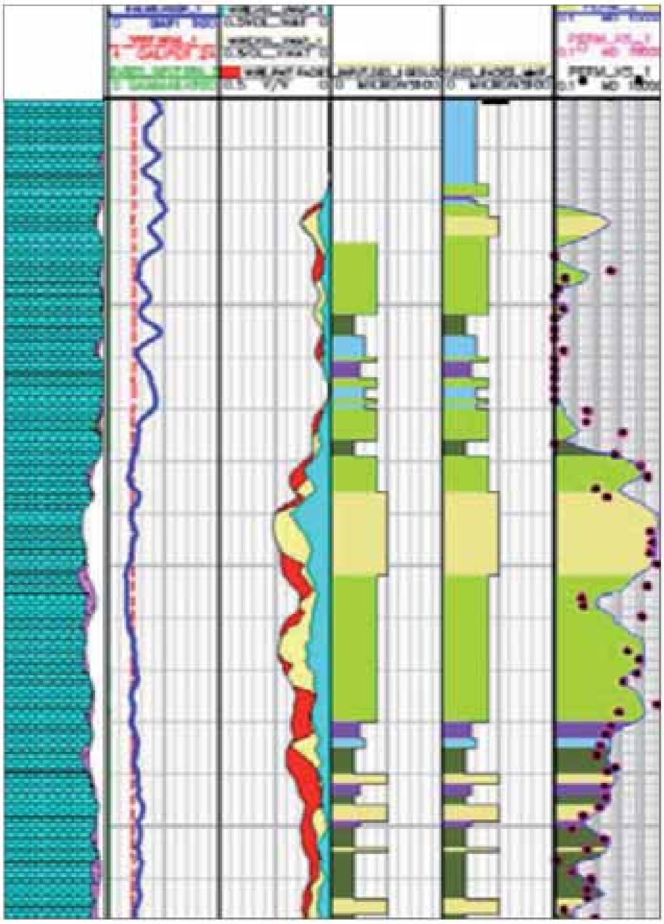

Fig. 9. Track 4 shows facies type based on core description. Track 5 is the facies propagated from the neural network, and Track 6 is a comparison between permeability of the model vs. core[4].

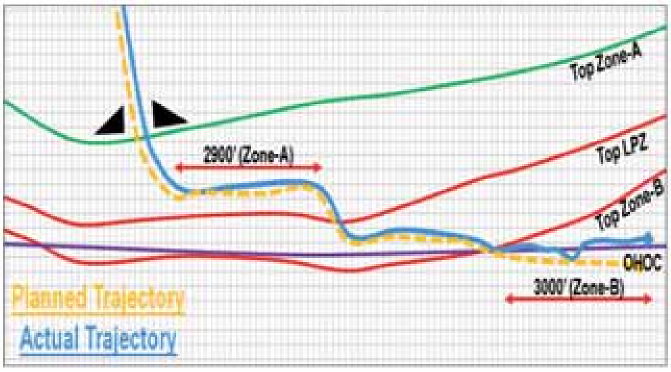

Fig. 10. Comparison showing planned and actual well trajectories. Formation tops presented are picked after drilling.

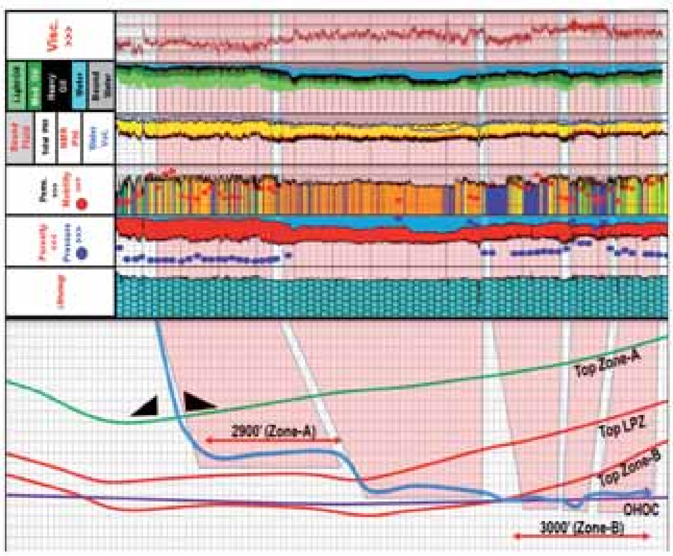

Fig. 11. Real-time petrophysical analysis used for geosteering. The blue curve indicates the actual well trajectory. The third track from the top presents the predicted permeability, where the hot pink color represents higher permeability, and the cooler green colors represents lower permeability.

tools justifiable and crucial to ensuring a successful injector.

Figure 10 illustrates the planned well trajectory and the actual trajectory after drilling the well. The injection section for Zone A was accurately planned and no major adjustments were needed while drilling. On the other hand, the plan of the injection section for Zone B is below the encountered heavy oil contact, which would have resulted in negligible injectivity. Adjustment to the drilling trajectory was made to place the well shallower than originally planned.

Figure 11 shows the real-time log analysis done during geosteering of the well. The open hole section for this well can be broken down into five sections:

1. This section shows the injection section for Zone A, which is confirmed by both high porosity, and modeled permeability. The FPWD confirms a uniform pressure and high mobility.

2. This section is drilled through the LPZ. The estimated total porosity is similar to Zone A in Section 1. The LPZ is confirmed by supercharged pressure points as well as low mobilities. Several consecutive "no seal" tests were observed.

3. This drilled section encounters Zone B, which is confirmed by the higher mobility and uniform reservoir pressure.

4. In Section 3, a constant inclination angle of 86° was held because it was believed that the OHOC was at a lower depth. The actual heavy oil contact was shallower than expected and confirmed by high viscosity readings, low mobilities, and supercharged pressure tests. The well was then turned upward to move away from the heavy oil zone. Without the NMR tool and the petrophysical analysis the geosteering team would not have fully concluded that they were drilling in the heavy oil section, and could have concluded that they are still in the LPZ.

5. After geosteering outside the heavy oil, it was advised to stay parallel to the OHOC.

Conclusions

The case study illustrates the importance of utilizing FPWD and NMR-WD to ensure a successful well placement in complicated geology and fluids. Advanced real-time petrophysical data analysis is crucial for geosteering in such reservoirs.

This case study illustrates that:

- FPWD can be effectively used to identify low permeability zones through low mobility and supercharged pressure tests.
- Consecutive tests with "no seal" or "lost seal" may be indicative of low permeability rocks due to the lack of time necessary for mud cake to build up.
- Pressure tests in the heavy oil section also result in supercharged pressures as well as low mobility estimations. This may mislead to confusing the tar mat with the LPZ.
- Zones with heavy oil/tar were detected using the in-house NMR algorithms to estimate in-situ oil viscosity.
- Predicted permeability and lithofacies from the neural network models are excellent indicators for real-time geosteering decisions.

Acknowledgements

The author would like to thank Saudi Aramco management for their permission to present and publish this article.

This article was presented at the 2012 Young Professionals Technical Symposium, Dhahran, Saudi Arabia, March 19-21, 2012.

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Biography

Majed F. Kanfar joined Saudi Aramco in 2010. He currently works as a Petrophysicist in Shaybah field. Majed has held several technical positions as a Petrophysicist in the Southern Area fields, Northern Area fields, and Special Study units in the Reservoir Description Division. His research interests are in reservoir geomechanics, unconventional gas, and reservoir saturation monitoring and dynamic petrophysics.

In 2010, Majed received his B.S. degree in Petroleum Engineering from the University of Kansas at Lawrence, Kansas. He graduated at the top of his class.

Majed joined the Society of Petroleum Engineers (SPE) in 2006 and has been an active member ever since. He also actively serves on the Young Professionals Student Outreach and Career Planning Team.

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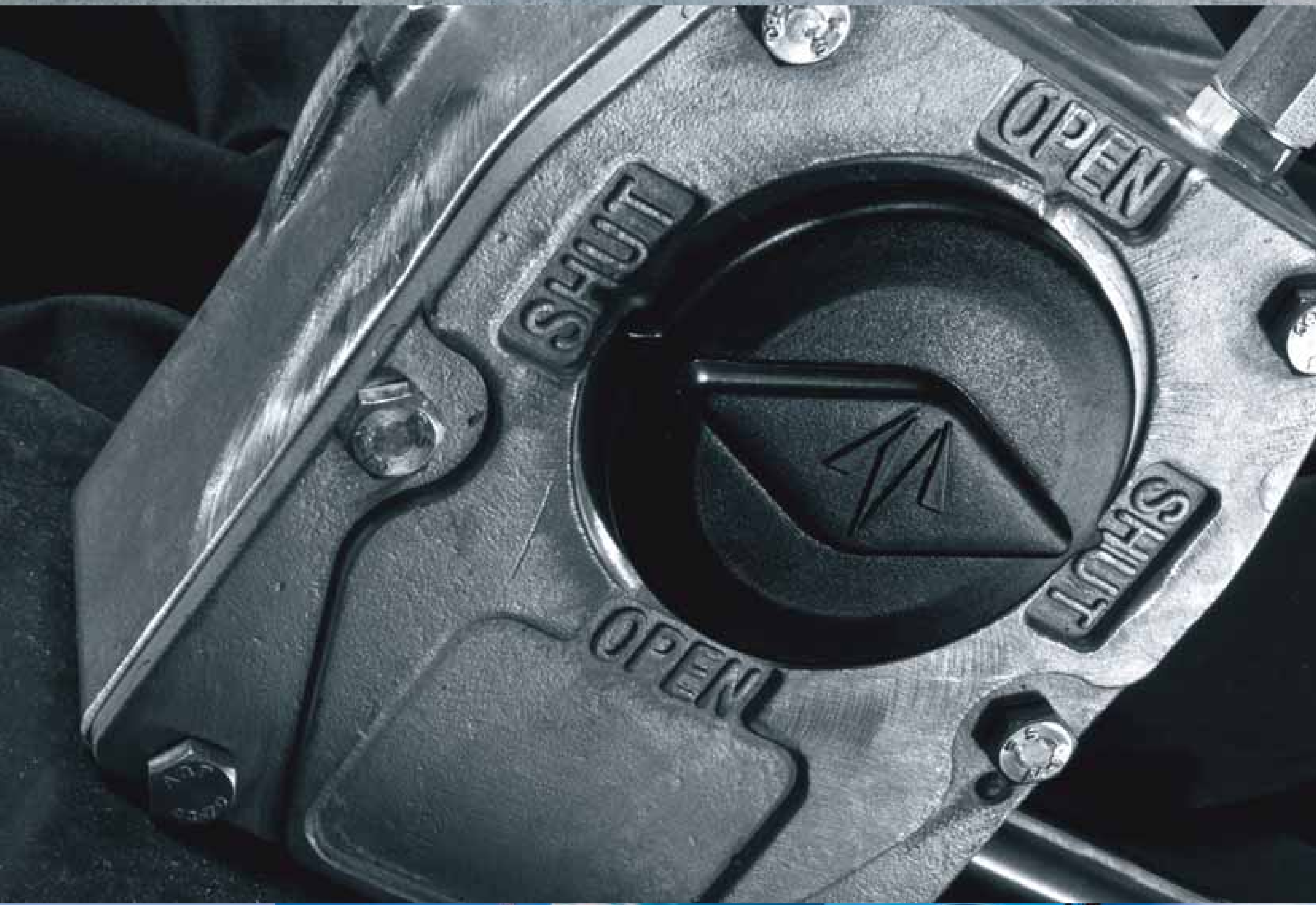

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Coiled Tubing Operational Guidelines in Conjunction with Multistage Fracturing Completions in the Tight Gas Fields of Saudi Arabia

By Mohammed A. Al-Ghazal, Saad M. Driweesh, Abdulaziz M. Al-Sagr, J. Tate Abel, Stuart Wilson and Bryan Johnston.

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Abstract
Open hole multistage fracturing completions are becoming standard practice in the southern gas fields development in Saudi Arabia, with more than 40 wells completed to date using open hole packers and selective port technology.

Overall, the production results from the use of multistage fracturing completions have been very positive, and the fore- cast is that multistage fracturing technology usage will grow considerably over the next several years. In general, multistage fracturing completions provide an excellent advantage in that they are intervention-less in their standard mode of operation. An evolving aspect of such completions is the secondary use of coiled tubing (CT) to handle the planned and unplanned (contingency) operations occasionally required to reach well production objectives. Without optimum operational planning and the selection of correct CT downhole tools, completion problems can be encountered, and this ultimately can result in not reaching the job objective at all or only at increased costs. In addition, the use of CT to function ball-activated ports to shut-off zones or to restimulate wells is starting to be appreciated.

This article presents multistage fracturing case studies where CT has been deployed, and then investigates the operational impact and productivity enhancement of CT deployment. Correlations taken from the key hardware variables, such as fracturing port size and type, motor type, mill type and CT size, are also considered and analyzed.

Following the lessons learned and best practices derived from these experiences, the findings from this article, with correct implementation, should increase the potential for successful multistage completion operations and ultimate improvements in productivity. These guidelines can therefore be transferable to other operators using similar multistage fracturing completion technologies.

Introduction
This article is intended to act as a guideline covering all relevant options in milling ball-activated port seats with coiled tubing (CT) in multistage fracturing completions. It should be noted that of the more than 10,500[1] multistage fracturing completion operations that have been performed worldwide, the milling of ball-activated port seats has been performed in fewer than 10%. The key reason is that in nearly all cases, milling seats is seen to add risk that outweighs the potential positive effect on hydrocarbon production. For this article, we will discuss cases where milling of the ball-activated port seats was necessary, and we will provide recommendations on the optimum bottom-hole assembly (BHA) tool string setup.

Since every application will vary with the well's size, depth, inclination and hole condition, this analysis is only a guideline, as it cannot cover all the potential issues involved in CT operations. As such, the intent of this article is to take the lessons learned from surface testing and field operations, and transfer this knowledge to operators for use in developing a successful milling program, given local well conditions, equipment availability and operator preferences. The use of local procedures for well and personnel safety, hole cleaning and CT conveyance should be followed as required for each application. This analysis is not intended to specify the selection of CT BHA tools, but to recommend the preferred and field proven options. The availability and selection of these tools will vary in each operation and remain the responsibility of the completion/ CT service company.

This article will discuss seat milling operations conducted during the past two years on ball-activated ports in four wells that involved multistage fracturing. Two different suppliers provided the ball-activated ports and these will be referred to as port suppliers A and B. Each of the ball-activated port suppliers provided the specialized mills to mill out the balls and seats of their ports.

Two different milling service suppliers were used and these will be referred to as milling suppliers A and B. The milling suppliers provided the complete BHAs, including the motors, used in the ball and seat milling operations.

Ball-activated Ports

All ball-activated ports used for multistage fracturing operations have a similar basic design: a seat is attached to a sleeve that moves downwards to open when a ball is on the seat and pressure is applied. Here is where the similarity ends, as there are many variations in seat materials and seat design, and ports may be designed for single or multiple operations. There are also several different types of ball materials, depending on conditions in the well during stimulation operations. All of these factors can affect the ease of milling out the balls and seats.

Seat Material

The seat should be made from a material that is able to resist corrosion and abrasion from wellbore and stimulation fluids, yet can be easily milled, if required. Seats manufactured from hardened steel address part of the equation – the material is resistant to corrosion and abrasion – but mill-out is difficult and time consuming. Port supplier A has developed a proprietary seat material that is both strongly resistant to corrosion and abrasion, yet easily millable.

Seat Type

If water breakthrough can occur, it is preferable to use reclosable, ball-activated ports so that zones producing water can be identified and shut off. If the well can benefit from future stimulation treatments, it is also preferable to use reclosable, ball-activated ports so that the additional stimulations can be performed. Seats for reclosable, ball-activated ports tend to be longer than single operation ports, increasing the need for easily millable material.

Ball Material

Depending on the application, balls are manufactured from different materials. Ball materials used for low temperature and low-pressure wells are different from those used for high temperature and high-pressure wells. The choice of material is based on the need to have a ball with sufficient fracture toughness and hardness to be pumped downhole at a high rate, land on the ball seat at a high velocity without any damage, open the ball-activated port and seal off the zones below. When the stimulation job on a zone is complete, the ball is no longer required, so the balls have to be either flowed back with the produced fluids or milled out.

As soon as the surface pressure has been released after stimulation on a zone is complete, the ball will move off the seat. With the added pressure and flow from the well production below, the ball will be further pushed off the seat and will not be a hindrance to hydrocarbon production. Following fracturing operations, ideally the ball will be pushed back to the surface during well flow back and initial production, where it will be caught by a ball catcher in the flow back line. Recovery of complete balls does happen in some situations; however, what has been seen in many field operations is that the balls appear to flow back part of the way and then reach a particular deviation in the well where they churn – pulled up by the produced hydrocarbons and down by gravity. As the balls are rapidly moved around in this way, they smash against the tubing and each other, and disintegrate over a short time. In most instances, only fragments of the balls are recovered in the ball catcher.

Disussion Points Regarding CT Milling Requirements

In some multistage fracturing cases, ball-activated port seat milling and/or ball milling is essential and must be planned in advance. These cases include:

- Water injector wells, where the balls cannot be flowed back and injection into all zones is required.
- Operations and/or interventions that require tools (e.g., logging, perforating or shifting tools) to be run to the lower part of the multistage fracturing completion immediately after stimulation treatments and before flow back.

In these instances, milling of only the balls should be considered first, leaving the seats intact so the ball-activated ports can be used for future operations. In all other cases, optional milling of both balls and ball seats can be considered and conducted on an as-needed basis. Multistage fracturing systems should be designed so that the seat's inside diameters (IDs) allow CT and logging tools to be deployed to total depth without milling out the seats.

The two positions of the ball seat within the ball-activated port are shown in Figs. 1 and 2. Following the initial fracturing treatment and when the pressure from above has been released, the ball will roll off the seat to allow production back to the surface during well flow back.

The proprietary material of the drillable, ball-activated port seat is strong and highly pressure and abrasion

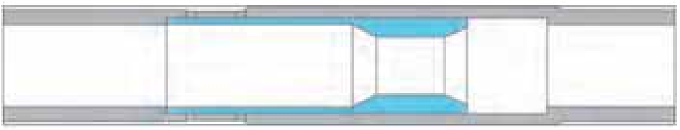

Fig. 1. Ball-activated port showing ball seat of a multistage fracturing completion: Closed/Initial position.

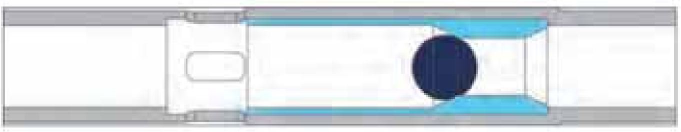

Fig. 2. Ball-activated port showing ball seat of a multistage fracturing completion: Open/Final position.

resistant, but it has low ductility and so is fairly brittle and easy to mill out.

Field Experience

Typically, as noted earlier, the balls for the ball-activated ports are flowed back to the surface when production is started. If the balls are not retrieved or if there is an obstruction, such as wellbore debris, in the ball-activated ports, the ball seats and balls need to be milled out.

Experience shows that the seats of both port suppliers A and B can be milled; however, the choice of mills and motors, as well as the time required, varies significantly. Port supplier A allows for multiple ball seat milling operations in one run, with or without the balls present in the system; however, with port supplier B, if the ball is on the seat, two CT runs per sleeve are required.

Four recent cases in the southern gas fields of Saudi Arabia were investigated and compared:

Well 1: Mill-out of two ball-activated ports (port supplier A, milling supplier A); Well 2: Mill-out of two ball-activated ports (port supplier A, milling supplier A); Well 3: Mill-out attempt of one ball-activated port (port supplier B, milling supplier B); and Well 4: Mill-out of one ball-activated port (port supplier B, milling supplier A).

Case Study Well 1

The objective was to mill-out two ball seats (port supplier A) in a single CT run (milling supplier A):

- Ball-activated port #1 at 16,472 ft, mill-out from 3” to 3.375” ID.
- Ball-activated port #2 at 16,853 ft, mill-out from 2.75” to 3.375” ID.

Following the milling recommendation given by port supplier A, a 3.375” 4-bladed starcutter mill was run below a 2.875” outside diameter (OD) high-torque motor. Each ball seat mill-out took approximately 45 minutes at moderate weight on bit (WOB); no stalls and no high-drag situations were encountered, Fig. 3.

The post-job plot shows the mill-out of the ball seats without a single motor stall. The mill approached the ball-activated port at approximately 5,800 psi off-bottom pressure. Once the mill engaged the seat, pressure increased to 7,250 psi on-bottom pressure and was kept steady while proceeding slowly. After 30 minutes, the ball seat was milled and a check trip performed. Motor performance at 1,450 psi differential pressure was approximately 1,050 ft-lb torque output at 45 horsepower (HP).

Case Study Well 2

The objective was to mill-out two ball seats (port supplier A) in a single CT run (milling supplier A):

- Ball-activated port #1 at 13,670 ft, mill-out from 3” to 3.375” ID.
- Ball-activated port #2 at 15,184 ft, mill-out from 2.75” to 3.375” ID.

The two ball seats were milled out with the recommended milling BHA: a 3.375” OD starcutter mill below a high-torque motor. The average WOB was higher than in Well 1 throughout the milling operation, resulting in faster rates of penetration (ROP). The upper seat was milled out in 25 minutes and the lower seat was milled out in 30 minutes, Fig. 4.

The post-job data shows a fast target approach and intentional motor stall to confirm the depth of the ball seat. The milling BHA was then slowly lowered at approximately 1,050 psi off-bottom pressure, which increased to 2,450 psi when the mill engaged the seat. With a motor load of approximately 1,000 ft-lb, the seat was steadily milled in approximately 25 minutes, without a motor stall.

Case Study Well 3

The objective of the intervention was to mill out a single ball seat (port supplier B) at 14,448 ft from 3.025” ID to 3½” ID. Milling services were provided by milling supplier B, with a 2.875” OD CT motor and a 3½” OD step mill. Repeated motor stalls were experienced immediately after the mill engaged the seat, and no milling progress was possible. High drag was observed when pulling up, indicating either that the mill

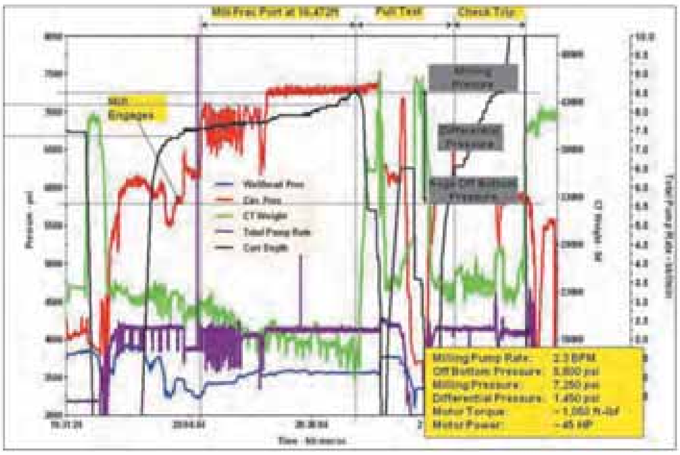

Fig. 3. Well 1: Milling out lower seat with starcutter mill – post-job plot.

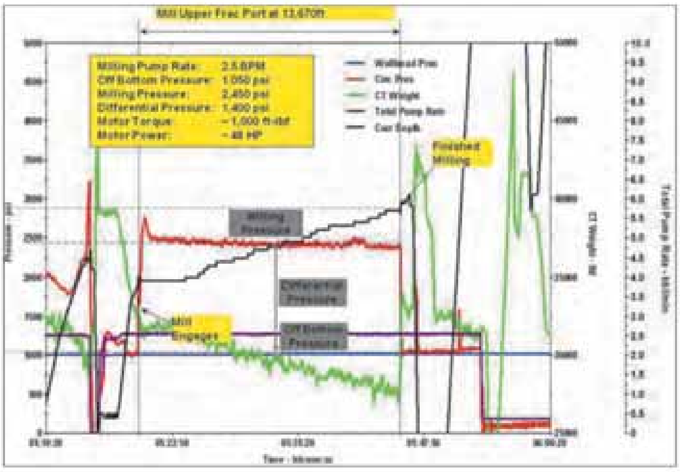

Fig. 4. Well 2: Milling out upper seat with starcutter mill – post-job plot.

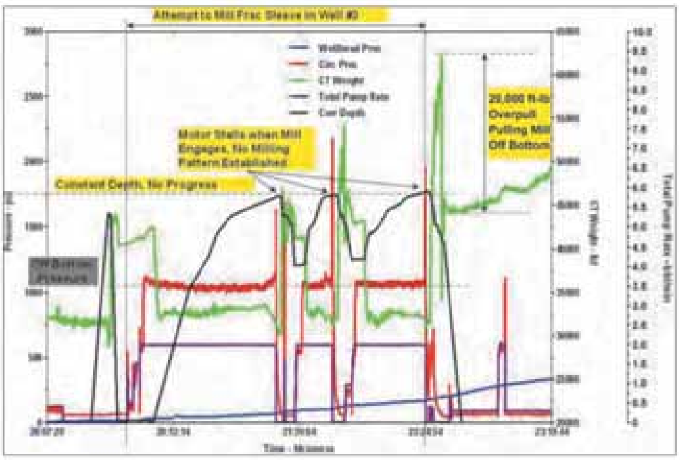

Fig. 5. Well 3: Unsuccessful attempt to mill out ball and seat.

was wedged in the seat, as opposed to milling the seat, or that the ball left in the seat had deflected the taper-shaped mill from the desired milling path. The mill-out operation was abandoned due to the risk of the mill's getting stuck and also the potential to damage the completion by creating an accidental sidetrack.

While approaching the ball-activated port, the pump pressure (off-bottom pressure) was constant and low, after which a sudden pressure spike was observed on all three attempts when the mill contacted the seat, Fig. 5. The pressure spikes resulted from the mill's locking into the seat and stopping the motor, thereby blocking the flow through the motor. The off-bottom circulating pressure remained constant and the motor stalled at the same depth, indicating that no progress was made. After the last milling attempt, an overpull of 20,000 ft-lb was experienced, showing the mill had become temporarily stuck.

During surface inspection, the mill showed no wear patterns at the bottom steps, but significant wear on the top section, Fig. 6. This indicates that the mill became jammed inside the port and explains the overpull experienced on the last milling run.

Case Study Well 4

Based on lessons learned from the previous mill-outs, the milling supplier on this well was changed to milling supplier A. The objective was to mill-out a 3.025" ID seat (port supplier B) to a 3½" ID.

Following a mill-out procedure provided by port supplier B, two unsuccessful runs were made: first using a 5-bladed flat-bottomed mill, then using a 4-bladed flat-bottomed mill, below a 2.875" OD high-torque downhole motor. On both runs, motor stalls were encountered and no milling pattern could be established. The mill-out procedure was revised to include a 4-bladed step mill, which is typically used to mill out nipple profiles or other very hard-to-mill materials. Running this special step mill on the third run proved fairly successful; however, the mill-out took approximately three hours at maximum motor torque output, Figs. 7, 8 and 9.

Seven stalls, indicated by sudden pressure peaks, were experienced when the mill made contact with the ball seat, Fig. 7. Even at a very slow target approach speed, it was not possible to make progress, indicated by the steady low pumping pressure (off-bottom pressure) and the motor's stalling at the same depth repeatedly.

Similar results were observed on four additional milling attempts, Fig. 8. The motor worked at low pressure during the target approach, then stopped as soon as the mill contacted the seat.

The post-job data plot, Fig. 9, shows the successful mill-out of the ball seat with a 4-bladed step mill. The first

Fig. 6. Picture of step mill after retrieval back to surface.

approach was performed with an intentional stall to confirm the target depth, and the seat was then milled out in three milling stages. The off-bottom pressure during the target approach was approximately 1,700 psi; it then increased to 3,200 psi on-bottom pressure when the mill was engaged. At 1,500 psi differential pressure, the motor put out approximately 1,100 ft-lb torque. The total time required to mill the sleeve was approximately 150 minutes.

The results of the case studies listed above are summarized in Table 1.

Discussion

Analysis of four recent ball seat mill-out examples showed significant performance variations.

Ball-activated Port "Millability" and Mill Selection

The seats of the ball-activated ports from supplier B are millable; however, operationally it was noted that they required a significant amount of preparation, runs and time to mill. This is because the ball seats are made from hardened steel. As such, a nonaggressive mill, such as a multiple stepped mill with precision carbide inserts, is required. Any aggressive mill will overload a high-torque motor, even at minimum WOB force. Mill-out time experienced was approximately three hours. With the ball still on the ball seat, two runs were required per port to achieve mill-out. The ball had to be milled with an aggressive flat-bottomed junk mill first, followed by a second run with a nonaggressive step mill. Combining the two runs is impossible because the taper-shaped step mill can be deflected off the desired milling path when the ball is on the seat, while the aggressive junk mill overloads (stalls) the motor immediately when milling the ball seat itself.

The ball-activated ports from supplier A proved to be readily millable in a short time regardless of whether the ball was still on the seat or not. Multiple balls and seats could be removed in one run. This is because the ball seats are made of a proprietary material that is hard, yet millable. The material can be milled in a short time with a semi-aggressive mill. A customized, 4-bladed junk mill with starcutter inserts provided by port supplier A is recommended. Mill-out time ranged between 25 and 40 minutes per seat when run in conjunction with a high- torque motor.

Motor and Mill Operational Performance Analysis

Motor selection proved to be a critical parameter when milling ball seats provided by port supplier B. Even with a nonaggressive mill, the seat material hardness caused the mill to stop rotating at minimal WOB (see Well 3, milling supplier B), and this in turn caused frequent motor stalls with little or no progress. Changing to a high-torque motor helped to rectify this condition, keeping the mill turning when high torque was required. Even with the high-torque motor working at maximum HP output, however, milling the hardened steel seat took significant time and patience.

Ball seats from port supplier A were found to be easily millable. In both cases that were evaluated (Well 1 and 2, milling supplier A), high-torque motors were run, and no stalls were encountered at high ROP. This leads to the assumption that these seats could potentially be milled with a standard motor, if it was required. High-torque motors are preferred because:

- The high-torque output keeps the mill rotating at high load (reduced number of stalls).
- No milling interruptions after motor stalls.
- Longer mean time between failures because reduced or no stall damage occurs (stator rubber decomposition, chunking).
- Higher ROP due to increased HP output.
- Chemical-resistant design allows for combining seat

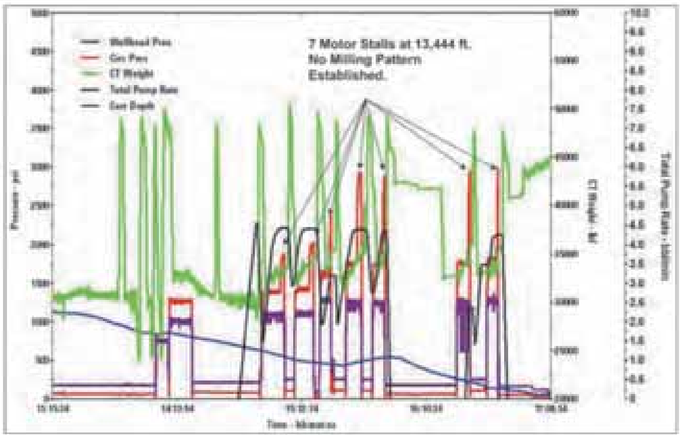

Fig. 7. Well 4: First run with 5-bladed flat-bottomed mill – post-job plot.

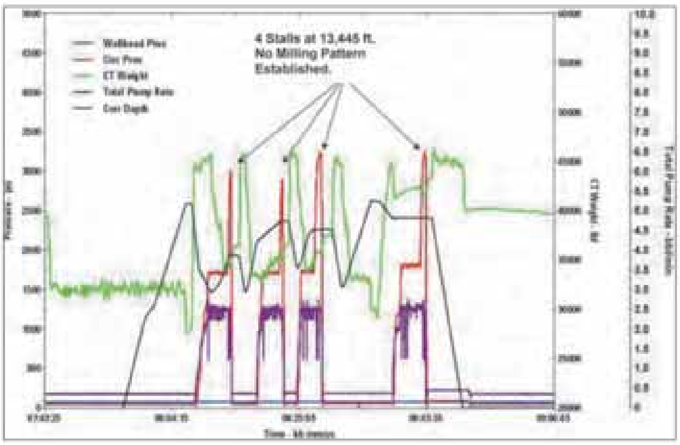

Fig. 8. Well 4: Second run with 4-bladed flat-bottomed mill – post-job plot.

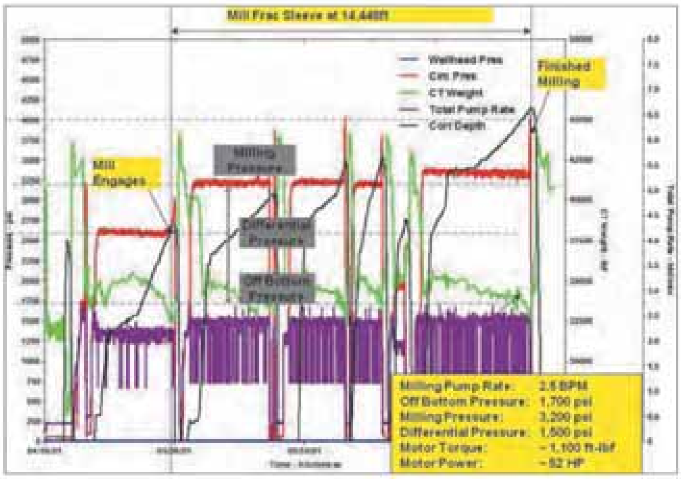

Fig. 9. Well 4: Third run with 4-bladed step mill – post-job plot.

mill-out with other job objectives (acid spotting, N2 lifts).

Recommended BHA for Multistage Fracturing Milling Operation

The recommended BHA for the mill-out of a ball-activated port ball seat in a multistage fracturing completion, Fig. 10, would be as follows:

- CT connector.
- Motorhead assembly (dual-flapper check valves, hydraulic disconnect and circulation sub).
- Hydraulic up-acting jar (optional).
- Circulation sub (optional).
- Nonrotating centralizer (recommended).
- Hydraulic high-torque motor.
- Starcutter mill.

Based on the extensive testing, field cases and general practices for milling with CT, the following recommendations can be made with respect to mills, motors, stabilizers and additional milling equipment. Note that the circumstances for each well will be different. As such, these procedures are not intended to cover every application, nor should they take precedence over local practices and procedures, especially with regard to health, safety and environmental issues; rather, they should be used as a guide based on previous successful operations.

CT Connector

A standard grub screw or slips type connector is recommended. A "roll-on" type connector is not recommended as it risks losing its grip on the CT string when used in conjunction with motors.

Motorhead Assembly

A heavy-duty, rigid motorhead assembly is recommended that incorporates dual-flapper check valves, a hydraulic drop-ball disconnect and a drop-ball circulation sub. A hydraulic disconnect should always be employed when milling in the event the BHA becomes stuck in the well. It also must be rugged enough to withstand the forces imposed during the milling operation. The separation section is actuated by dropping a ball and pumping it through the CT string to a ball seat in the hydraulic disconnect tool. When the ball seats, the BHA is placed in tension and pressure is applied to shear the pins connecting the two portions of the hydraulic disconnect. The lower portion of the hydraulic disconnect remains in the well; it incorporates an internal fishing neck, which facilitates fishing operations. The upper portion is retrieved to the surface. Once milling is complete, it may be desirable to increase the pump rate to clean up the well or pump nitrogen to unload the well. This increase in pump rate is accomplished by bypassing the motor to eliminate rotation and the friction pressure drop. The circulating sub is positioned below the hydraulic disconnect so that the separation section can still be actuated after the circulation sub is opened, if required.

	Well 1	Well 2	Well 3	Well 4
Port Supplier	A	A	B	B
Depth, Port #2	16,472 ft	13,670 ft	14,448 ft	13,400 ft
Depth, Port #1	16,853 ft	15,184 ft	-	-
Mill Supplier	A	A	B	B
Mill Type	3.375" Starcut-ter Mill	3.375" Starcutter Mill	3.500" OD Step Mill	3.500" OD Step Mill
Mill Details	4-Bladed Flat-bot-tom, w/ Starcutter Inserts	4-Bladed Flat-bot-tom, w/ Starcutter Inserts	4-Bladed, w/ Carbide Inserts	4-Bladed, w/ Carbide Inserts
Mill Character-ization	Semi-ag-gressive	Semi-ag-gressive	Non-ag-gressive	Semi-ag-gressive
Motor Type	High-Torque Motor	High-Torque Motor	CT Motor	High-Torque Motor
Maximum Torque	1,100 ft-lbf	1,100 ft-lbf	-	1,100 ft-lbf
Maximum hp	52 hp	52 hp	-	52 hp
Milling Time, per Port	45 min per Seat	25 min and 30 min per Seat	Could not Mill Seat	3 hours for 1 Seat
Job Result	Success on 1st Run	Success on 1st Run	Failure	Failure on 1st and 2nd Run, Success on 3rd Run

Table 1. Summary of the four wells analyzed from field operations.

The circulating sub may be actuated by dropping a ball and pumping it through the CT string to the ball seat in the circulating sub, or by applying high circulation pressure alone. In the ball-drop design, when the ball seats, the BHA is placed in tension and pressure is applied to shear the pins, allowing an internal sleeve to shift and expose large circulation ports.

Stabilizers/Centralizers

The use of a stabilizer is recommended as part of the milling assembly. The stabilizer should have an OD between 0.125" and 0.25" smaller than that of the mill to allow drifting through an obstacle that is milled. The stabilizer allows for a better centralized milling operation and more efficient cuttings removal during milling (e.g., in horizontal wells, where the tool could be lying on the low side of the well and so restrict cuttings flow back). In restricted wellbore applications, the motor OD may approach the mill size. In these cases, the use of a stabilizer is of limited benefit and therefore optional.

Hydraulic Motor

In the majority of cases, as large a motor as possible should be run for the milling job. Certainly the motor OD needs to be at least one size (~0.25" to 0.125") smaller than the mill OD. The OD is initially dependent on the minimum restrictions in the well, as with the mill, but also the annular clearance between the motor OD and the tubing/casing ID needs to be considered to ensure good flow passage of the debris being returned to the surface.

For a given size motor, it is recommended to choose a high-torque motor over one with high rotational speed when a hard object, such as a ball seat, will be milled. Generally, the torque increases with the number of stages and the number of lobes in the rotor/stator assembly. The speed decreases as the number of lobes increase. High speed is not efficient if the feed rate and WOB cannot be controlled effectively, as the motor will constantly stall.

Often, the initial issue for the milling program is to address the available CT size and length. This will greatly affect the selection of the milling BHA. While all motors will generally operate over a wide range of flow rates, it is essential to check that the motor will function with the optimum torque range for the flow rates available. A large, high-torque motor is not effective if the available flow rate is too low. CT force simulations should be run to check that sufficient WOB is available. If tubing forces simulation results indicate potential weight transfer problems, a metal-to-metal friction reducer may also be considered.

Mills

The recommended mill type is a 4-bladed end mill with down facing holes for circulation. The OD of the mill is dependent upon the ID minimum restriction in the well (e.g., upper R-Nipples, etc.); otherwise the mill OD will be determined by the liner/tubing drift ID or the mill-out ID of the ball-activated port. It is important that the mill have a long body or shaft, to allow for better stabilization of the mill and to reduce the risk of having the mill end fall into recesses and mill on non-drillable components of the ball-activated port.

Recommendations and Conclusions

Selection of Ball-activated Ports

If removal of the seats from ball-activated ports is anticipated, or even a potential requirement, it is important to deploy ports that are designed for easy mill-out. Hardened steel seats are not easy to mill, and if the ball is still on the seat, a separate run is required to first

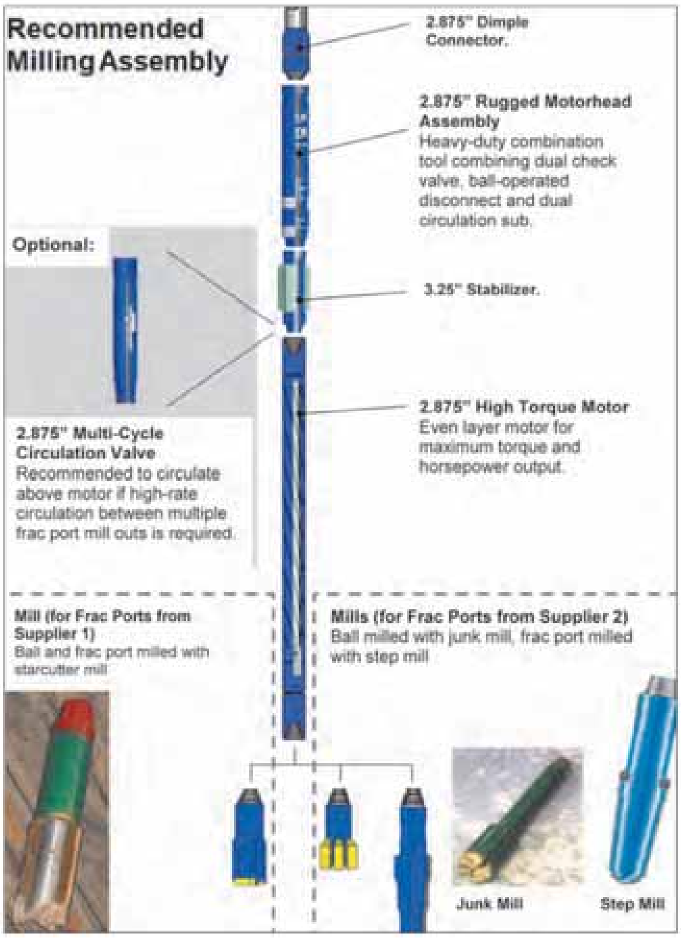

Fig. 10. BHA diagram showing the component options for CT milling of ball- activated seats.

remove the ball. Then a second run with a different mill is required to remove the seat. In addition to the time and cost of a second CT run, much time is required to mill the hardened steel seat. If hardened steel seats have to be removed from multiple ports, two runs will be required for each port.

When ball-activated ports with seats engineered for mill-out are deployed, a single mill can be used to remove the balls and seats from multiple ports in a single run.

Selection of Mill

Each supplier of ball-activated ports will have recommenda- tions for the mills to use for milling the seats from their ports. The most efficient seat and mill combination found to date is the starcutter mill used on the proprietary engineered seat (port supplier A). The starcutter mill can mill through multiple balls and seats in a single run.

Selection of Motor

High-torque motors are preferred over standard motors. For mill-out of ball seats from supplier B, a high-torque motor is mandatory to achieve success. Mill-out of ball seats from supplier A could be performed with standard motors; however, using high-torque motors reduces milling time.

High-torque motors from milling service supplier A have proven successful at milling out all types of ball seats. The high-torque output is achieved by higher differential pressure, which is made possible due to the even layer of rubber lining the stator. These motors can be used in high temperature applications, if nitrogen-assisted cuttings lift is required or even if aggressive chemicals have to be spotted.

Selection of BHA

The CT BHA for milling ball seats from ball-activated ports should include a dimple connector, a circulation sub, an emergency disconnect and a stabilizer. Milling services supplier A includes a circulation valve in their BHA to provide a contingency for removing cuttings during ball seat mill-out. The circulation valve can be switched from milling mode to cleanout mode by adjusting the pump rate.

Contingencies/Efficiency

As with any milling operation, removal of cuttings and hole cleaning is crucial to reduce the risk of loading up the annulus and becoming stuck. Best practices developed include circulation of high viscosity pills or sweeping the wellbore after milling out several ball seats. Nitrified gel can be pumped to transport cuttings in low bottom-hole pressure wells or to increase cutting transport velocity.

Acknowledgements

The authors would like to thank the management of Saudi Aramco, Schlumberger and Packers Plus Energy Services for their permission to present and publish this article. The authors would also like to thank Maria Meijer and Marco Dutra at Packers Plus Energy Services for their assistance in the preparation of this manuscript.

This article was presented at the SPE Middle East Unconventional Gas Conference and Exhibition, Abu Dhabi, U.A.E., January 23-25, 2012.

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Biographies

Mohammed A. Al-Ghazal is a Production Engineer at Saudi Aramco. He is part of a team that is responsible for gas production optimization in the Southern Area gas reserves of Saudi Arabia. During Mohammed's career with Saudi Aramco, he has participated in several upstream projects, including pressure control valve optimization, cathodic protection system performance, new stimulation technologies, safety management processes and petroleum applications enhancement.

In 2011, Mohammed assumed the position of Gas Production HSE Advisor in addition to his production engineering duties.

In early 2012, he went on assignment with the Southern Area Well Completion Operations Department, where he worked as a foreman leading a well completion site.

In 2010, Mohammed received his B.S. degree in Petroleum Engineering from King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia. He has also authored and coauthored several SPE papers and articles in technical publications.

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Abdulaziz M. Al-Sagr is a Supervisor in the Southern Area Production Engineering Department (SAPED). He has been very involved in the gas development program in the Southern Area to meet the growing global gas demand. Abdulaziz's experience covers several aspects of production optimisation, including acid stimulation, coiled tubing applications and fishing operations.

In 1995, he received his B.S. degree in Chemical Engineering from King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia.

J. Tate Abel is a Senior Petroleum Engineer working for Saudi Aramco in the Gas Production Engineering Division. Before joining Saudi Aramco, he spent 3 years as a consultant for numerous independent oil and gas operators in North America and for several state-run E&P companies in India. Tate has over 17 years of workover/completion and project management experience in the Middle East, North America and Asia.

He received his B.S. degree in Chemical Engineering from the New Mexico Institute of Mining and Technology, Socorro, NM, and a MBA from Centenary College, Shreveport, LA.

Stuart Wilson is a Stage FRAC Manager for Schlumberger Well Services in al-Khobar, Saudi Arabia, responsible for the marketing and technical development of the company's multistage fracturing completion business throughout Saudi Arabia and the Middle East region.

After earning his B.Eng. degree in Mechanical Engineering from the University of Hertfordshire, Hertfordshire, England, and his M.Eng. degree in Business and Operations Management from the Norwegian Institute of Technology, Trondheim, Norway, in 1997, Stuart joined Schlumberger as a Field Engineer in Stavanger, Norway. He worked 5 years in various technical and operational positions in Norway and Denmark. From 2002 until 2005, Stuart served as the worldwide product champion for the Schlumberger coiled tubing (CT) inflatable packer business.

In late 2005, he became the GeoMarket Technical Engineer in Moscow, covering CT operations in the Russia area. In 2006 until late 2007, Stuart worked as the CT Operations Manager for the Far East-Russia GeoMarket region in the Sakhalin area, working on several projects, including Lunskoye.

From 2008 until taking his current post in 2009, he served as the multistage fracturing completion product champion based in Dubai, U.A.E., covering the Middle East and Far East regions.

Stuart is the author of several papers on multistage fracturing, inflatable packers and CT offshore technology. In 2003, he was named a World Oil New Horizons award finalist.

Stuart is a member of the Society of Petroleum Engineers (SPE).

Bryan Johnston is the Business Development Coordinator for Packers Plus, serving the Middle East Gulf countries. He has worked in the oil services industry for 20 years in operational, technical and marketing positions, and is experienced in cementing, stimulation and downhole tools, Bryan worked for Dowell Schlumberger as a Field Engineer, then as an Operations Supervisor and District Manager. He worked with McAllister Petroleum Services, the manufacturer of inflatable packer products, as Marketing Manager. When that company was acquired by Weatherford, Bryan worked in sales and business development positions within Weatherford before joining Packers Plus in 2006.

He received his technical diploma from the British Columbia Institute of Technology, Burnaby, British Columbia, Canada, and an MBA degree from the University of British Columbia, Vancouver, British Columbia, Canada.

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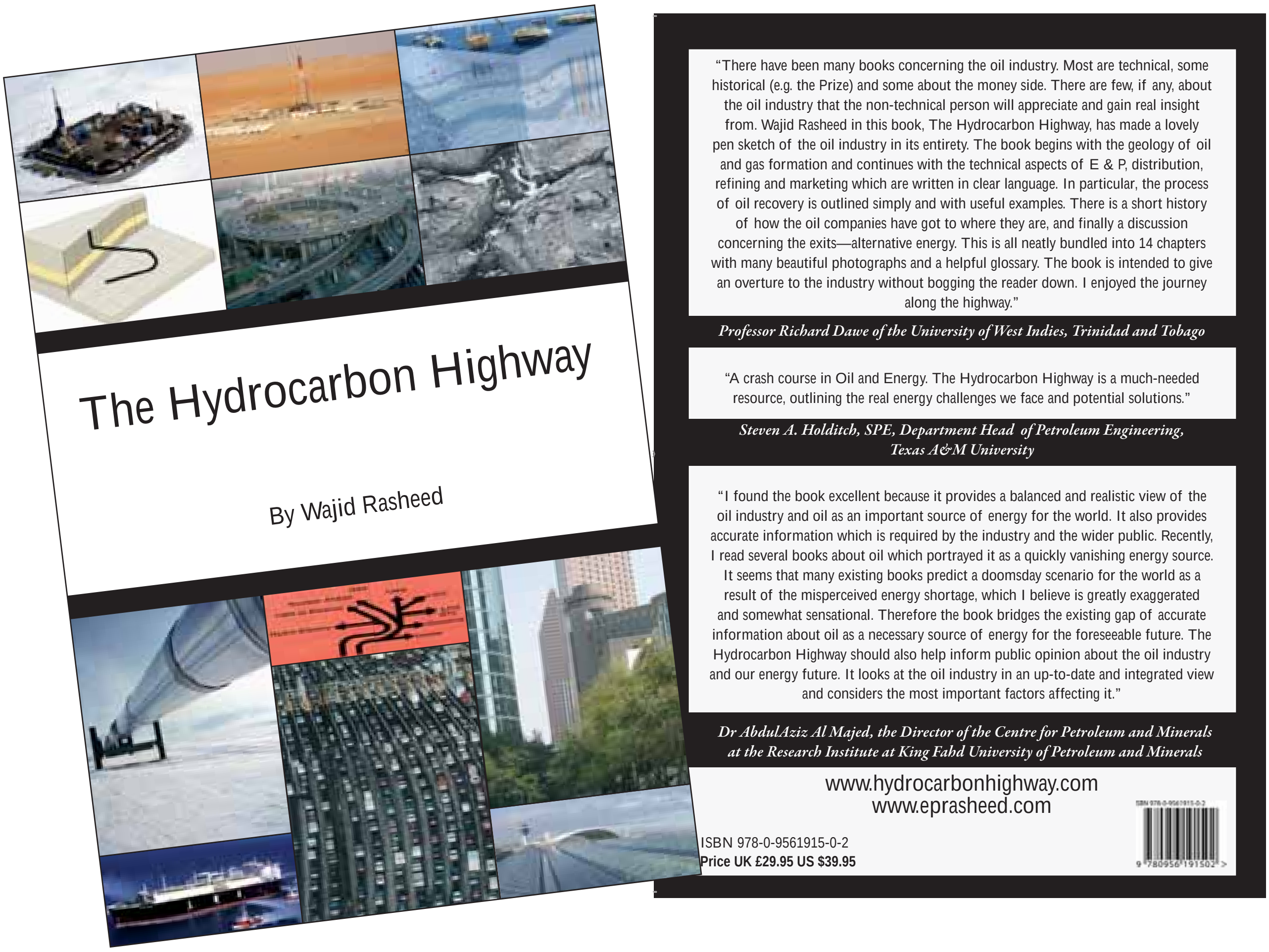
Properties, Players and Processes



Clearly, the most prized possessions in the industry are the leases allowing access to giant oil and gas fields; however, these fields must be found and this entails risk. This chapter looks at the background of how oil companies come to possess oil and gas 'properties' and the processes and players involved in their development.

Bids and Blocks

Acreage, blocks and concessions all refer to a legally recognised interest in an oil and gas property. This is surrendered by a land owner in exchange for royalties and other considerations. Despite the fact that most oil and gas deals are confidential business transactions, almost all are bid for openly. The final contract and choice of the oil company will depend on the nature of the land owner and development complexity[1].

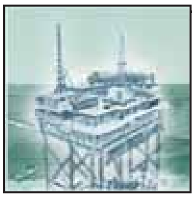
Land Owners

Governments have different obligations from institutions, which in turn have different needs to those of private individuals. Governments are driven

FPSO Platforms - Floating, Production, Storage and Offloading vessels (FPSOs) can process and store crude oil, and offload the oil and/or natural gas. A process plant is installed on the ship's deck to separate and treat the fluids from the wells. After the crude is separated from the water and gas, it is stored in tanks on the actual vessel and then offloaded to a relief ship every so often.

The relief vessel is an oil tanker that moors on the FPSO stern to receive the crude stored in its tanks and then transport it onshore. Compressed gas is sent onshore through gas pipelines and/or injected back into the reservoir. The larger FPSOs have a daily processing capacity of some 200,000 barrels of oil, with an associated gas production of approximately two million m^3 a day.

Round-Hull FPSO - This is a pioneering FPSO platform due its round-hull shape, and the first to produce, store and offload oil. The platform produces in deep waters, ranging from 1,000 to 1,500 metres. The round shape increases stability in the sea, since the waves circle the vessel. Its hull, made out of two layers of steel plates, is more versatile and stable, allowing operation under much more severe environmental conditions and affording the vessel more safety with regard to oil leakage into the sea.



Fixed Platforms - These were the first units to be used. Preference has been given to them in fields located in water depths to 200 m. Fixed platforms generally consist of modular steel structures installed at the operation site with piles driven into the seabed. Fixed platforms are designed to receive all drilling equipment, material storage, and staff accommodation, plus all well-production facilities.

Jack-Up Platforms - These consist basically of a barge fitted with a support structure, or legs that when activated mechanically or hydraulically, are lowered until they reach the seabed. The platform is then raised above the water level to a safe height, away from the action of the waves. These platforms are mobile and are pulled by tugboats or are self-propelled. They are designed to drill exploratory wells on the continental shelf in depths varying from 5 to 130 m.

Semi-Submersible Platforms - Semi-submersible platforms consist of a structure of one or more decks supported by submerged pontoons. A pontoon moves in accordance with the action of waves, currents and winds, and this may damage the equipment that is to be lowered into the well. That is why it must be set in position on the surface of the sea, within a tolerance radius dictated by the sub-surface equipment. Two kinds of system are responsible for positioning the pontoon: the anchoring system and dynamic positioning system.

The anchoring system consists of 8 to 12 anchors and cables and/or chains, like springs that produce efforts that can put the pontoon back in position when it is moved by the action of the waves, winds and currents.

In the dynamic positioning system, there is no physical connection between the platform and the seabed, except in relation to the drilling equipment. Acoustic sensors determine the driftage, while the computer-controlled propellers in the hull bring the platform back into position.

Semi-submersibles may or may not be self-propelled. In any event, they are more mobile and are preferred for drilling wildcat wells.

Drill Ships - A drill ship is a vessel designed to drill subsea wells. Its drilling tower is located midship, where an opening in the hull allows the drill string to pass through. The drill ship positioning system, consisting of acoustic sensors, propellers and computers, cancels out the effects of the wind, waves and currents that tend to move the ship from its position.

Figure 1 - Types of Platforms (Courtesy of Petrobras)

by a much wider agenda ranging from economic sustainability, obligations to future generations and social responsibility. Institutional and private individuals are generally more concerned with a Return on Investment (ROI) within a given time period[2].

Development Complexity

The cost and complexity of a particular development depends on its location, size and the extent of geological knowledge. If the lease is offshore, greater complexity and cost will be added. This is because offshore fields require more capital, technical expertise and logistical planning than onshore fields. The rule of thumb is the greater the water depth, the greater the complexity and cost, as higher specification rigs are required.

Developments that are located in shallow waters (defined as up to 1,500 ft or 500 m water depth to the seabed) may use fixed platforms. Greater complexity is associated with developments located in deep seas (up to 6,560 ft or 2000 m of water) as they require tension leg platforms or semi-submersible rigs. The greatest technical and financial challenges are linked with ultra-deepwater developments located in water depths of 8,200 ft (2500 m) or more. In these water depths, semi-submersible facilities or Floating Production, Storage, and Offloading (FPSO) vessels are required[3].

Block size will also add complexity and cost. Typically, offshore Gulf of Mexico (GOM) blocks are nine square miles in size. Offshore North Sea block sizes vary between 230 and 460 square miles. Blocks in new exploratory frontiers can be much larger. Exemplifying this are Brazilian exploratory blocks such as those in the Foz de Amazonas which can be 2000 square miles in area. Locating reserves in such a large area is no mean feat.

Where geological knowledge exists, exploration risk is reduced. Where previous wells have been drilled, reservoirs and conditions have been characterised and this acts as a guide to future drilling; however, in wildcat or exploratory wells where reservoir characterisation is not present, complexity, cost and risk are increased.

Royalties

A 'royalty' is an interest in an oil and gas lease that gives the owner of the land the right to receive a portion of the production from the leased acreage or proceeds from the sale of production. This generally does not require the owner to pay any portion of the costs of drilling or operating the wells on the leased acreage. Royalties may be either land-owners' royalties or overriding royalties. Land-owners' royalties are reserved by the owner of the leased acreage at the time the lease is granted. Overriding royalties are usually reserved by an owner of the leasehold in connection with a transfer to a subsequent owner. Royalties can vary from 100% in the case of national companies, to 50% in joint ventures and to as little as 10% in mature assets. The level of royalty depends on the complexity of the development and investment required. Royalties are not necessarily the most important aspect of an oil and gas deal as creating local content and infrastructure may be equally important[4].

Producers seek exploration and development assets in order to maintain a return to shareholders. Market watchers apply considerable weight to proved reserves and production when analysing share values. They are the long-term measure of an oil company's health, while daily production represents short-term cash flow.

Portfolios Balance Risk

How do oil companies routinely back some of the most expensive and risky ventures on earth (i.e. deepwater exploration drilling) and still make profits? Oil companies can sustain the heavy losses of a wildcat (drilling for unproven reserves with limited geological knowledge) because they have a portfolio of assets generating cash. This is usually managed on the basis of markets, geography and economics. Oil companies employ geological modelling, offset data and exploratory wells to pinpoint reserves. Both oil companies and concession holders use due diligence systems to appraise certain blocks (a lease area inland or offshore) according to historic finds to date or the likelihood of finding oil and gas. Where no wells have been previously drilled, the oil company will drill a wildcat. This represents the highest degree of risk, but can be balanced with finds and production from other mature assets generating cash. The portfolio is usually split along regions, countries and assets. It is here that market conditions prevail. Oil companies will use financial models that take into account the future value of hydrocarbon reserves at different barrel price scenarios and demand. Oil companies will apply financial models assessing economic and production variables such as the '3 Ps' and the present value of reserves[5].

Gaining a Concession

Land owners attract attention to prospective offerings or licensing rounds by informing industry analysts and firms specialising in oil and gas leases. They may also conduct 'road-shows' where key members of the land owners management will present 'upstream opportunities' at industry events such as the International Petroleum Conference, the World Petroleum Conference and at financial centres around the world.

Subsequently, and without exception, all land owners will pre-qualify companies with an invitation to tender. Strict technical and financial criteria are applied before this initial application for a concession is accepted. In this way, concession holders (governments, institutions or private individuals) can screen prospective oil companies or 'operators' to see that they are actually capable of meeting the challenges associated with the exploration and production of hydrocarbons and pay the all important royalties.

> The greatest technical and financial challenges are linked with ultra-deepwater developments located in water depths of 8,200 ft (2500 m) or more.

Once a prospective operator has been qualified, they can then proceed to the next stage. Qualification leads to bidding or negotiating the contract for lease acquisition. Further steps will be seismic permitting, lease option negotiations, and preparing pooling and unitisation agreements. It should be noted that unitisation agreements are usually only entered into after discovery and some production has taken place. This usually occurs when the collective area operators realise that their field can produce more oil as a single unit rather than several sub-units. Negotiating a unitisation agreement is incredibly complex, particularly in the case of land leases where a large number of land owners are involved. Typically, this is an open auction, sealed bid or a negotiated deal. Open auctions are competitive bids for leases, sealed bids are posted and closed negotiations are held between parties. Each has its merits and downfalls; sometimes more can be negotiated off the bidding table rather than on the table[6].

'Producers-88' Lease Form

Although there is no standard form of oil and gas lease, a common form for US oil and gas leases is known as the 'Producers 88'. The name arises from an oilman or 'producer' who was seeking to purchase a lease. This producer had a certain deal in mind, but had no printed contract outlining the terms and conditions. The oilman sought a printer's shop to get the form printed. The printer's foreman needed to give the printing job a name and pencilled in 'Producers-88' to the job referring to its sequence in the press. Due to an oversight, the pencilled reference was printed on the upper left-hand corner and the name stuck, 'Producers-88' lease form.

Not every producing company used the same printer, but anecdotes show that many farmers (land owners holding the title deeds) would only sign a 'Producers-88' form of lease. Consequently, majors, independents and 'land-men' had their own forms of leases printed, many of which were similar in content, but all of which had 'Producers-88' printed in the upper left-hand corner.

The pre-printed form of lease typically presented to a mineral owner has basic terms and provisions such as the name of the land owner and oil company, the description of the land, the duration of the lease, the amount (fraction or percentage) of royalty, the name of the depository bank for the payment of rentals, and the amount of rentals (if it is not a paid-up lease)[7].

> "Negotiating a unitisation agreement is incredibly complex, particularly in the case of land leases where a large number of land owners are involved."

'Paperweights'

There is no single form of lease that meets all land owners' specific needs. Each lease is a bulky set of documents prepared on an individual basis. Usually, the oil company will have to accept the bid lease conditions offered, but in certain cases (i.e. for a multi-billion dollar investment) negotiating leeway exists. Conditions will cover the granting of a lease, royalty, shut-in well, pooling and unitisation, delay rental and partial release, operations and offsetting production, assignment, warranty, and force majeure clauses.

On entering an oil concession, the land owner and oil company have different interests. The land owner is interested in gaining as much bonus, royalty and terms such as local capability as possible. The oil company is interested in limiting its obligations to the land owner and wants the lease to contain terms that are as broad as possible. In most instances, the parties will compromise to reach a mutually acceptable middle ground and a contract will be signed[8].

Bargaining Power

As in all business transactions, the party with the greater bargaining power and knowledge sets the terms. It has been said that governments, at times, can be at a negotiating disadvantage when dealing with International Oil Companies (IOCs). At any given time, IOCs can draw on a much wider knowledge base of global trading conditions. In contrast, a national government is limited to national conditions. This was part of the rationale for the nationalisation of petroleum in many countries and the formation of the Organisation of the Petroleum Exporting Countries (OPEC). Nonetheless, land owners will always hold the upper hand because they 'own' the oil and gas reserves. Oil companies need reserves to keep trading so they are willing to 'buy' the technical and financial risks associated with exploration and pay royalties; however, neither can profit without the other as there is a mutual need.

Today, gas exporting countries have formed alliances to share information on global gas trends. This experience shows that granting access to oil and gas rights are strong bargaining tools which can help obtain benefits beyond royalties[9].

The Oil Is Ours... But You May Develop the Gas

Some twenty-five years ago, the Saudi royal family

> "The oil company is interested in limiting its obligations to the land owner and wants the lease to contain terms that are as broad as possible."

finished the process of re-nationalisation of the country's oil and gas reserves. This allowed Aramco, the national oil company, to join a growing group of oil companies and countries that re-nationalised their hydrocarbons; for example, countries such as Mexico, Venezuela and Iran. By some accounts, between 1970 and 1976, nearly 20 countries asserted their national sovereignty over their operations. Driven by the need to develop gas reserves (to meet the growing demand for gas and to keep oil for exports), many countries have slowly relaxed their national controls. This has been accomplished through joint ventures, contracts with service companies and ownership licences which allow larger oil companies to return to previously nationalised oil markets[10].

Many types of oil and gas contracts exist. In this section, we consider the process of selecting and contracting oilfield service companies.

It is worth distinguishing oil and gas operating contracts from service and supply contracts. We have already seen how operating contracts provide a framework for paying hydrocarbon production royalties (bids and blocks). Now, we can consider how service contracts enable the supply of equipment and technical services that are necessary for hydrocarbon production.

Outsourcing

Traditionally, oil companies whether IOCs, NOCs or independents have always out-sourced certain oilfield activities, such as rig supply or facilities engineering. As the industry consolidated in the 80s and 90s, the volume of outsourcing increased as new definitions of non-core activities were applied to a greater number of activities and disciplines. Nowadays, non-core activities are defined differently according to the discipline and oil-company in question; however, the common thread that emerges is that all disciplines will have at least some outsourced elements. This means that any given oil company will have service providers in many different areas of activity. The extent of actual outsourcing depends very much on the culture of the oil company, the degree to which a task is defined as core and its accompanying level of commercial sensitivity.

Core Activities

Facilities engineering, for example, is an area that is traditionally outsourced. Certain oil companies,

> "Traditionally, oil companies whether IOCs, NOCs or independents have always out-sourced certain oilfield activities, such as rig supply or facilities engineering."

however, may consider production or drilling and completions as non-core. In this case, an oil company representative will act as a project manager, but the actual engineering is conducted by a lead service company and a number of sub-contractors. Other oil companies may consider disciplines such as reservoir management as core areas, or as sensitive functions, and therefore not wish to outsource the service. Almost all operators consider exploration and reservoir management as core to their operations because these two activities can make or break a company[11].

Major oil and gas disciplines are classed as:

- Facilities (platforms)
- Drilling and completions
- Production
- Reservoir engineering
- Health, Safety and Environment (HSE)
- Management systems (IT and Accounting)
- Project management, and
- Project economics/financing.

Oil Service and Supply Companies

Fortune 500 Top 15 Oil Companies

Table 1 shows the top 15 oil companies that are listed by the Forbes Fortune 500 group and floated on the New York Stock Exchange (NYSE) or other American stock markets as of 2007. With the fall of the Oil Curtain, we can expect more NOCs such as Sinopec, CNPC, Petrobras, Pemex and StatoilHydro to move higher up the table.

Many of the large service companies are floated on the Philadelphia Stock Exchange; however, some companies such as Schlumberger, Halliburton, Baker Hughes and Weatherford are also listed on the NYSE. The Philadelphia exchange runs an Oil Services Index (OSX℠) which is price-weighted and comprise companies that provide oil drilling and production services, oil field equipment, support services and geophysical/reservoir services. The OSX commenced trading on February 24, 1997.

Some OSX companies are:

1) Baker Hughes Inc. (BHI)

2) R&B Falcon Drilling Company, Inc. (FLC)

3) Global Industries Ltd. (GLBL)

4) Halliburton Co. (HAL)

5) Nabors Industries Inc (NBR)

6) Noble Drilling Corporation (NBL)

7) Rowan Companies, Inc. (RDC)

8) TransoceanSedcoForex (RIG)

9) Smith International Inc. (SII)

10) Schlumberger Ltd. (SLB)

11) Tidewater, Inc. (TDW), and

12) Weatherford (WFT).

National Factors

Many service companies can trace their origins to as far back as 50 years ago, and in some cases, as much as a century. These companies will have built up strong positions in technological niches and markets through organic growth as well as acquisitions. Their positions will be based on local applications, relationships, investment and management philosophy.

Variations in market presence occur due to political situations, governmental policy and the trading regulations between countries; therefore, certain service companies will be stronger in certain markets and enjoy a leadership position, while in other geographic areas they will have only a skeletal presence. In this way, the service sector tends to balance itself out globally with the larger companies tending to consolidate their market share in certain areas while being weaker in others. This occurs with giant service companies such as Baker Hughes, Schlumberger and Halliburton. One or more of these service companies may have a large market share in Latin America and the North Sea, while having a reduced presence in the Middle East. By the same token, the other service company's operations will reflect the opposite; it will have a stronger presence in the Middle East and a lower presence in other areas[12].

Operator Type

Large IOCs such as Shell and BP will always tend to favour centralised service agreements due to the high number of operating assets these companies hold. A central procurement contract offers global supply and pricing advantages which will have been negotiated by a head or regional office with bulk volumes in mind. Many such contracts exist and are aptly named such as the 'Big Lever', 'Preferred Contractor' or the most popular term these days, Master Service Agreement (MSA). The oil companies will also appoint local focal points which enable the contracts and services to be managed more effectively and in accordance with local needs.

For certain products that can be bought in bulk such as casing, bits and drilling fluids, this provides certainty of business on both sides. Independents may also develop global preferred service agreements but, due to a much smaller number of operating assets, their contracts will be less centralised and will tend toward establishing contact with major service companies on location[13]. Sometimes smaller oil companies may form 'co-ops' to purchase commonly-used items in bulk to get a low price. They usually do this thorough the auspices of an area supply store.

Process of Selection

Despite the oil and gas industry being highly globalised, most of the factors that influence the selection of contractors are locally based. These include variations from nation to nation, operator type, the extent of goodwill between companies, technical innovation and price. The actual selection of contractors is a complex process that requires oil companies to appoint a project manager or other executives to act as a tender board in order to prepare a contracting strategy.

This document will cover: the prequalification of tenderers; a finalised bidders' list; finalised technical and commercial specifications; the preparation and issuing of a tender document; bid clarification; issuing of clarifications and addendum to tenderers; prepation of company estimates; the evaluation of technical and commercial bids; presentations to the project manager or tender board; presentations to the Ministry that deals with oil and gas leases; the awarding of contracts; start up (mobilisation); and budget calculations among other things. Corporate governance, ethical standards and local content targets are also often included[14].

Typically, IOCs will employ a global focal point or a project or technology leader with responsibility for the contracting strategy and direction. Each region or major asset will also have a local specialist or focal point. This local specialist will have a local service company counterpart. Other staff will include service personnel seconded to the oil company's local offices[15].

National Oil Companies

NOCs are more likely to contract long-term services

Rank	Company	500 Rank	Revenues ($ millions)
1	ExxonMobil	2	347,254.0
2	Royal Dutch Shell	3	318,845.0
3	BP	4	274,316.0
4	Chevron	7	200,567.0
5	ConocoPhillips	9	172,451.0
6	Total	10	168,356.7
7	Sinopec	17	131,636.0
8	China National Petroleum	24	110,520.2
9	ENI	26	109,014.2
10	Pemex	34	97,469.3
11	Valero Energy	43	91,051.0
12	Petrobras	65	72,347.0
13	Statoil	78	66,280.3
14	Repsol YPF	90	60,920.9
15	Marathon Oil	92	60,643.0

Table 1 - The 15 Top Oil Companies as Listed by the Forbes Fortune 500 Group

and develop partnerships with service companies. NOCs, despite the perception to the contrary, provide many of the most lucrative service contracts. The predominant philosophy or perception is that 'the lowest price wins'. This may be applicable in some cases, but in general, the NOCs often offer long-term fixed revenue contracts, something that IOCs rarely offer.

Some NOCs are obliged under the laws of their country to accept the low bid. This can cause problems as many fly-by-night companies deliberately lower a bid to get the work or concession and try to figure out later how they are going to fulfill its terms.

Goodwill

This concept covers global relationships that permit the exchange of technology, knowledge and operational know-how. These relationships exist at many levels. Some oil companies use bulk-buying contracts to supply international operations, while others use Joint Industry Projects or JIPs. Other oil companies rely on technology cooperation agreements and personal relationships with their service company counterparts and small specialised companies.

Small companies may not achieve large economies of scale, but at the same time they do not have large overheads. Because they can act rapidly, they can often beat the giants when it comes to developing new technology. Operators develop technology in-house through JIPs and with best-in-class companies; for example, Shell and Petrobras respectively are involved in the monobore and the Procap 3000 initiatives which are two examples of technology cascading downward.

Underlying the monobore (a vision of drilling and casing a single-diameter well from top to bottom) was the creation of two businesses to develop the downhole tools, tubes and markets for expandables. Procap 3000, a range of exploration and production technologies, is paving the way in ultra-deepwater development. Drilling contractors have introduced simultaneous drilling and completion of two wells by way of the dual-activity derrick system. Additionally, the billion-dollar think tanks and research and development facilities that major service companies own are continually creating new technologies.

So how do small companies compete against this

> A central procurement contract offers global supply and pricing advantages which will have been negotiated by a head or regional office with bulk volumes in mind.

backdrop? How do they succeed without the benefit of marketing channels or the influence of larger service companies?

Small companies can distinguish themselves by providing a service that includes applications analysis, technical recommendations and rig-site support through end-of-well reporting[16].

If they can maintain market leadership, they will attract the attention of operators interested in new technology. Certain oil companies select market leaders in what they deem essential technology and work with those leaders to develop new technologies (tough luck if you're not No. 1) .

Tangled Thicket

Traditionally, the oil company appoints a lead service contractor who may or may not be responsible for naming a drilling unit provider. The complexity of the drilling unit required will also affect whether this decision is made by the lead contractor or oil company. Drilling units (e.g. drillships, jack-ups, semi-submersibles or land rigs) will vary according to offshore and onshore needs. Subsequently, specialist contractors in each activity of each discipline are selected. As very few companies can provide all the required services, the concept of integrated contracting becomes commonplace. An integrated contractor or contracting alliance allows for each party to calculate their share of the development cost and price. These calculations are then used as performance targets, with the gain or pain of reaching or not reaching the target being shared. For operators fed up with the tangled thicket of contracts and contractors, the easiest course may lie in integrating outsourced services. This certainly reduces some of the complexity and numbers of service providers by providing a single point of contact. The appropriateness of integration, however, is very much dependent on the location and nature of the project; for example, the right approach for a development in China is probably inappropriate for Brazil. Other examples include the US GOM and the UK North Sea where contracting differs from practices.

Critics would argue that integration tends to discourage small-company services, as the main service provider will fulfil most technology requirements in-house. Only where technology is unavailable can a small company enter the project, filling a gap that no other

> "The actual selection of contractors is a complex process that requires oil companies to appoint a project manager or other executives to act as a tender board in order to prepare a contracting strategy."

business can.

Integrated services often mean small companies are required to meet wide-ranging legal or other tender requirements, many of which are applicable only to the major service provider. While safety is non-negotiable, it seems unfair to insist on the same levels of insurance liability for two different scopes of services. This asks small companies to bear more project risk without an accompanying increase in the reward[17]. Recently, IOCs have recognised the benefits of 'chain-of-accountability' and weigh this highly in contractor selection. Instead of dealing with a myriad of small providers, they limit their contracts to a few large, integrated service providers. If anything goes wrong, there is no finger-pointing. The contractor takes responsibility and fixes the problem.

Price – Market Cycles

Market cycles affect pricing more than any other aspect. In terms of tender strategy, an operator may use price competition as a way of controlling costs. In a down market, demand falls while the need to maintain utilisation remains. Here price-beating, where the lowest price wins, may be adopted by the service company to retain work. In an up-market, demand is increased and there are greater demands on utilisation; therefore, price competition is counter-productive as companies will tend not to provide services or equipment as they are diverted to the highest-paying markets.

Performance Pricing

How does one reward so many different service companies? Perhaps this is where value or performance pricing can help. The operator and small company set a performance target and price the work accordingly. If the contractor overachieves, they receive a proportion of the gain.

Conversely, if the contractor underachieves, they invoice less than the original price. It is self-evident that operators and small companies need to work more closely in developing cost-lowering technology. Increasingly, drilling engineers are becoming project managers rather than specialised engineers. Essentially, it lies with the service provider to effectively market service benefits to the operator.

This is where small companies trip up. Without established marketing channels, small companies regularly miss out on opportunities. Operators can help by focusing a small company's resources on specific projects where applications are plentiful.

> Underlying the monobore (a vision of drilling and casing a single-diameter well from top to bottom) was the creation of two businesses to develop the downhole tools, tubes and markets for expandables.

Cynics would argue operators are not in the business of making small companies richer, but this misses the point.

Sign-posting a project helps accelerate product development and operator savings. To that end, small companies must improve their marketing to demonstrate service benefits.

They must also develop partnerships with operators and be service-oriented rather than supply-oriented. Operators need to keep on the lookout for small companies, invest in their technology and encourage integrated service providers to use their services. Last, but not least, everyone must reassess how the reward is spread across the hydrocarbon machine[18].

Bundled or Bungled Services

It's easy to see the attractions of 'bundling' services. By integrating contracts for equipment and services, you can reduce suppliers and paperwork. In this way, fewer demands are made on your time, there is less paperwork, and there is less debating over which tool caused the trip.

Bundled contracts, however, can quickly become 'bungled' if individual Bottomhole Assembly (BHA) components and their risks are not isolated. Everything hinges on achieving a balance between risk and reward[19].

Service companies have been saying for years that the scales have tipped the wrong way. As in the past, oil companies still own acreage and all the geological or other problems it may have. Whether the reservoirs are hard-to-access, hard-to-locate or bounded by hard-to-drill formations, the challenges are inherited by the oil company. Yesterday's IOCs, that mainly kept their full internal Research and Development (R & D) facilities, could grapple with the difficulties by using in-house R & D 'greenhouses'. Shareholders didn't mind this. In fact, it was universally agreed that R & D investment was a way of maintaining a competitive edge; however, many modern oil companies do not necessarily have this resource any longer.[20].

Consolidation in the oil industry drove this change. Profits could be handsomely boosted by reducing expenditure in various things, not least in-house R & D. Today's IOC must look outwards for technology and this where the service companies fit in perfectly.

The service company's concern–read gripe, if you are an operator–is that although they solve an increasing

> "Integrated services often mean small companies are required to meet wide-ranging legal or other tender requirements, many of which are applicable only to the major service provider."

number of operator 'owned' problems, and run R & D facilities previously only undertaken by operators, rewards have remained constant over the years. Sure, rental or operating rates for equipment increase annually or have a premium according to location, but these are localised factors rather than a redistribution of reward based on risk acceptance and investment in research.

Everybody agrees that maximising oil production is the most important and valuable activity for the operator; however, nobody agrees about how to define and apply the true value of a particular activity. Mostly, the industry does simple maths: costs plus margin equals price. This, however, omits the true value delivered–or not–to the operator[21].

If you don't deliver, you get hit with the penalty, a lower value invoice. While this sounds good in theory, there are drawbacks. Standard drilling service contracts allow for separated BHA component risks. That's a grand way of saying if you're a drill bit (or other) company and some other downhole tool screws up, your final bit invoice won't be affected. And quite rightly–why should it? If the bit is performing fine, but a trip is caused by another element in the BHA, the bit company won't lose out.

In an integrated contract, this type of situation causes losses at an operating/meterage and at an overall performance level. Let's continue the example. Not only does the bit company suffer a loss in revenue due to another BHA component's failure, but there is also a lower overall performance for section drilled time. This invokes a penalty clause and it is not so easy to claim extenuating circumstances if all the equipment is supplied under a single company's service contract.

Things get even more complicated with the contracting of third party niche suppliers. If the equipment doesn't work properly, who bears responsibility? Worse still, what happens if this malfunctioning leads to a stuck fish or Loss-in-Hole (LIH)? On the note of LIH, it's worth straying a bit. It can be said that LIH prices are high. Certainly, a tool that is new and has only seen a few hours downhole will always have a high LIH price because this is a function of future revenue loss. Conversely, you must account for depreciation. If the tool had many hours utilisation, it should have a much lower value.

Let's get back to our stuck fish. It causes a sidetrack and a heavier than expected LIH invoice. Bang goes any incentive for the bit's good performance. Who bears the responsibility? If the Authority for Expenditure (AFE) is exceeded, who pays the difference?[22]

> Performance pricing would reflect costs (e.g. R & D manufacturing, tool wear and tear, etc.) and some part of the value delivered to the client.

These are tough questions and some might say somewhat extreme; however, they are based in reality. Although using a main contractor approach where a single company drills and completes the entire well is not yet commonplace, this is a growing trend. The remaining dilemma is as follows: how can risk and reward be shared between the many different service components?

Perhaps performance pricing can help. The operator and main contractor set a performance target and price the work accordingly. If there is overachievement, all receive a proportion of the gain. Conversely, if a component company underachieves, it invoices less than the original price and takes a proportion of the loss. Performance pricing would reflect costs (e.g. R & D manufacturing, tool wear and tear, etc.) and some part of the value delivered to the client[23].

An appreciation for the dilemma faced by operators has been a long time coming. For many years, oil company departments were semi-autonomous and had little regard for the other departments in the company. The drilling department was responsible for drilling a hole in the ground and casing it. The hole (one could hardly call it a well at this point) was then turned over to the completions department. The drilling department started to drill the next well, leaving the completions department to remedy such problems as formation damage caused by poor drilling fluid selection, bad cement jobs, damaged casing or wellhead problems.

The formation of asset teams alleviated these problems. By holding every member of the asset team responsible for the asset and rewarded solely based on the asset's performance on production, people such as drillers suddenly got a stake in the end result, and their sloppy performance came back to bite them in cost overruns or curtailed production performance; a lower asset profitability meant a lower bonus for them. The same fate awaited the geology department whose sloppy work caused a well to be drilled in the wrong place.

We know who the major players are in the oil industry and how they came to acquire their 'properties'. Now we need to know how do asset teams strike oil?

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6. Dependent on the oil company and land-owner involved.

7. May vary from lease to lease.

8. Negotiation plays as important a role as the bid.

9. Such as building local content.

10. Such as Brazil, Mexico and Saudi Arabia which all had monopolies.

11. Fundamental to asset management.

12. From the 30 countries I have worked in this is very much the case.

13. Idem.

14. Corporate governance requirements are often stipulated as contractual terms.

15. Also known as in-house engineers.

16. Harts E & P Mar 2002 Drilling Column Wajid Rasheed. 'Small companies and tangled thickets'.

17. Idem.

18. The reassessment of risk and reward seems to have stopped at percentage of value delivered or percentage operational cost.

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20. Although this may change as IOCs seek to differentiate themselves. Shell selects certain start-ups through its technology ventures (STV).

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23. In a low oil price some service companies may prefer to take greater risk. Others would shun this as unthinkable.

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