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2013 – Issue 33

Saudi Arabia oil & gas

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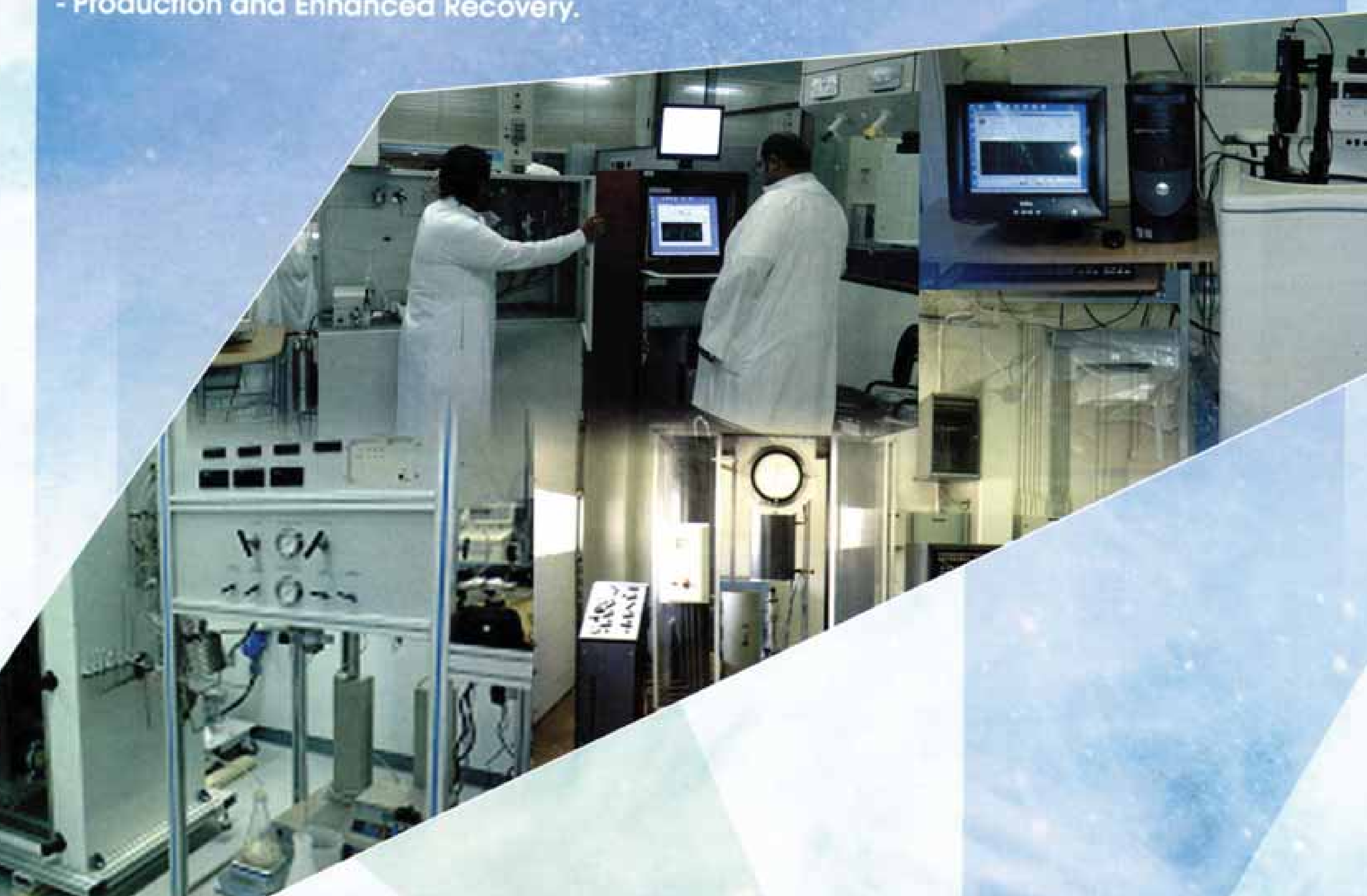
SPE ATS&E 2013 REVIEW

مدينة الملك عبدالعزيز
للعلوم والتقنية KACST

Oil and Gas Research Institute

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

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



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Manifa: Achieving the Dream

Khalid A. Al-Falih, president and CEO of Saudi Aramco, is joined by Abdulrahman F. Al Wuhaib, senior vice president of Downstream; Mohammed AbdulKarim, manager of Manifa Projects; Ali Nojaim, manager of Manifa Producing; Nasir K. Al-Naimi, vice president of Northern Area Oil Operations; and staff in the Manifa Control Room.

MANIFA, Saudi Arabia, 6 May 2013 – What should you expect on a visit to Manifa, Saudi Aramco's latest crude oil increment? With 41 kilometers of causeways built to connect 27 islands, each of which is larger than a soccer pitch, and 13 offshore oil-production and water-injection platforms, there are many potential surprises.

But the biggest surprise is probably the sheer number of young professionals everywhere, excited and proud at the launch of Manifa. "We recruited a large number of young Saudis through the Apprenticeship Program," said Abdulrahman Al-Qahtani, superintendent of Manifa Central Processing Facilities. "They completed their training at similar plants in the Northern Area.

"These young men were supplemented with seasoned employees who oversaw all the work assigned to them while maintaining the strictest safety and quality standards," he added. "This process yielded astonishing results as we actually managed to transfer knowledge and expertise in a practical and professional manner, all of this leading to the smooth commissioning of Manifa, on time and without incident."

Al-Qahtani added that Manifa reached the operational phase in record time.

Saudi Aramco's proud achievements at Manifa are countless. The most important, however, is that Manifa is operated by an all-Saudi workforce. There are about 55 engineers of all disciplines from various Saudi Aramco departments who came to Manifa, bringing with them their knowledge and expertise.

Mohammed Abdulwahid, superintendent, said, "We are proud of the young technicians' achievements, even though more than 70 percent of them have less than five years' experience."

He added that the average age of employees is between 19 and 25 years, but they have proved to be up to the challenge.

With a processing capacity of 900,000 barrels per day, Manifa is one of Saudi Aramco's largest oil producing fields after the 1.2 million barrels per day Khurais facility.

Manifa, however, stands out among its counterparts

> … we actually managed to transfer knowledge and expertise in a practical and professional manner, all of this leading to the smooth commissioning of Manifa, on time and without incident.

because of its energy self-sufficiency, as it co-generates 420 megawatts of electric power together with steam. Manifa is also unique because of its recycling of 3 million standard cubic feet per day of flare gas.

Oil wells, irrespective of their size though, require skilled manpower to operate, maintain and monitor them. All of this is done at the Control Room where Farraj Al-Subaiey works. He is a 26-year-old employee who completed the Apprenticeship Program in 2008. He worked at Safaniyah for six months, then at the Karan field for one year before being assigned to Manifa.

Alongside Al-Subaiey is Sultan R. Al-Qahtani, who joined Manifa in 2012. Al-Qahtani's role included preparing for the commissioning of the plant.

Originally from Tathlith near Wadi ad-Dawasir in the South, Al-Qahtani says he joined Saudi Aramco, "Because it is the largest industrial company and because it gives each employee the opportunity to develop himself both professionally and academically.

"I, for example, look forward to completing my education and majoring in mechanical engineering. Not only that, I plan to do post-graduate studies, all thanks to Saudi Aramco and the learning and development opportunities it gives its people."

How can anyone work in such remote areas and still display a perpetual shining smile, maintain a joyful spirit and keep their eyes focused on both the present and future with confidence and optimism? The answer is exemplified by Muhammad S. Al-Shammari.

"We had to preserve the area's marine environment with its beauty and wonders, reefs, the various types of fish, shrimps, etc.," the young senior offshore operations engineer said of Manifa. "All needed protection, and protection was what Saudi Aramco provided," he said. "All the implemented designs for the causeway, the sea islands and the marine platforms complied with global safety and environmental protection standards."

At the same time, safety is also a critical issue. Before Abdullah A. Balkhyoor joined the Manifa project, he split his time between Jiddah and New York State University in Buffalo where he graduated with top honors in chemical engineering. Balkhyoor joined

> When it comes to developing young people – particularly new engineering graduates – there is no disputing the fact that Saudi Aramco sets the bar.

the College Degree Program while in New York and became a company sponsored student. In Manifa, Balkhyoor is responsible for ensuring that operations are carried out safely and that every device and tool functions correctly and safely before commissioning.

When it comes to developing young people – particularly new engineering graduates – there is no disputing the fact that Saudi Aramco sets the bar. Such development is done through the three-year Professional Development Program.

These enthusiastic young employees are an indicator of the health of the Kingdom. Their words vibrate with self-confidence, with an attachment and admiration for the company, assuring they will give it their all to ensure the plant functions to its fullest capabilities.

After more than seven years of incredible effort, the commissioning of the Manifa project has given light to the whole area, said Yusuf H. Al-Shehri, senior representative in Operations, who accompanied us during our two-day trip.

In 2008, Saudi Aramco launched its vision and developed the general layout of the Manifa Plant, starting with the retirement and removal of the old, limited-capacity Manifa Plant. The Manifa Program immediately started to recruit and train scores of young engineers and operators to smoothly operate the plants which extend onshore and offshore.

"The Manifa story represents a heritage dating back to 1966," said Al-Shehri. "And here you have it, young people giving a distinct touch of modernity through the magnificent feats they have accomplished."

Remarks at Offshore Technology Conference

By Khaled Abdullah Al-Buraik, Vice President of Petroleum Engineering & Development, Saudi Aramco.

HOUSTON, TEXAS, 6 May 2013

"Good afternoon, ladies and gentlemen.

Thank you for your very kind introduction. I'm delighted to see so many friends and associates from around the world gathered for this outstanding industry conference.

And it's always a pleasure to be back in Houston, a great center of energy business and technology innovation.

Over the course of three decades in the oil and gas industry, I've witnessed many positive developments in the quest to meet the world's growing demand for affordable energy. As eventful as all these years have been, I must say that I consider the present moment to be the most exciting time in my memory for our industry and especially for Saudi Aramco.

This is because Saudi Aramco is undergoing a strategic corporate transformation – spanning every function of the company and including major new business areas.

There's new urgency as well as new optimism about where we're going. In the past we've been focused primarily on crude oil and gas; now we are progressing to become fully integrated -- in gas production, including unconventionals, refining and chemicals.

Today, I'll be focusing on our transformational efforts in technology development, in particular in the upstream.

At Saudi Aramco we're pushing forward from a traditional role as buyers and consumers of technology to our new global technology and R&D strategy. We envision becoming an enabler and creator of new technologies.

Let me stress that our outlook on R&D and technology development is strategic, and long-term.

This is consistent with our development plans for our oil and gas fields – allowing us to maximize reservoir performance, and add further value to our integrated energy value chain.

The same far-reaching time horizon applies to our investments in both talent and technology. We're

> “In reservoir engineering, our areas of focus include: enhanced oil recovery; the fundamentals of pore-scale physics; waterflooding using modified water or “SmartWater”; and unconventional resources.”

emphasizing high impact technologies that typically involve long-range strategies. We’re pursuing R&D to bring about breakthrough achievements --- not simple or merely incremental enhancements.

Our upstream R&D roadmap includes the characteristic subsurface technology domains:

• The geosciences, both geophysics and geology,
• Drilling, production and reservoir engineering, and
• Computational modeling.

Our other surface/facilities related R&D - refining and chemicals - are handled by our Downstream researchers and technologists.

Our focal points of research were carefully selected through a rigorous process based on the greatest potential business impact addressing our highest priorities.

For example, in geophysics we’re focusing on many long-term areas from seismic acquisition to multi-geophysics. Each of these areas has far-reaching vision and targets.

We’ll be probing and striving to find answers to key questions that are crucial to our ambitions, such as:

• Can we acquire four times the data yet reduce acquisition time and cost by 50%?
• Can we achieve five foot seismic resolution at 15,000 feet deep?
• Can we invert the Full Wave form … in just a day instead of weeks?

With a partner, CGG, we’re looking to robotics and autonomous underwater vehicles. This new offshore seismic acquisition platform should substantially reduce cost and time, while providing enhanced subsurface images.

In reservoir engineering, our areas of focus include: enhanced oil recovery; the fundamentals of pore-scale physics; waterflooding using modified water or “SmartWater”; and unconventional resources.

We have a long term vision and goals for these areas as well:

• Can we increase recovery by 15 to 20%?
• Can we measure reservoir data with high accuracy? For example, reservoir saturation to plus or minus 5% at 1,000 feet away from the well?

> "Our research focus areas under computational modeling include reservoir simulation, basin modeling and simulation, massive visualization, and modeling of unconventional resources."

We're continuing the development of our reservoir nanoparticle program. The program has two objectives. The first is for the injected particles to help us characterize and describe reservoirs better. The second is to increase recovery.

We've already conducted a major field test of our in-house manufactured nanoparticles. This year we'll conduct two major field tests. One will focus on enhancing reservoir characterization, the other on recovery.

As for our computational modeling technology, we have our own simulator, GigaPOWERS, fully developed in-house. Our research focus areas under computational modeling include reservoir simulation, basin modeling and simulation, massive visualization, and modeling of unconventional resources.

We'd like to simulate our reservoirs in the highest resolution possible. Yet to be effective, we need to do it efficiently. Can we simulate a one billion cell model in one minute?

Can we use GigaPowers computational engine for basin simulation to model a 10 billion cell representation of the Arabian Peninsula? Can we combine this with 500 million years of history to better guide our exploration program? This vision is not far away.

Let me shift gears to unconventional.

Historically our research and development focus has been on conventional. However, now we're moving into new frontiers – unconventional. The pursuit of unconventional gas is one of our most exciting new efforts.

We're focusing on three major regions in the Kingdom. In the Northwest, the search is characterized by shale at shallow depth. In the East, excellent tight gas opportunities have been identified for appraisal, and we could lower costs by leveraging our existing infrastructure. In the Southeast, prospects are economically attractive given the existing petroleum system.

Technology has revolutionized the industry to meet challenges and unlock this unconventional resource. Just look at the shale gas plays here in the U.S.

We know that our success in the Kingdom with unconventionals will depend on an integrated solution between geosciences and engineering.

> As part of our environmental stewardship, we are establishing an environmental center in collaboration with KAUST to conduct research related to the marine environment of the Red Sea

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Deep interdisciplinary efforts will be essential:

• To better characterize these resources;
• To stimulate, fracture and better mobilize hydrocarbons; and
• To model fluid flow.

Given our local infrastructure, the availability of water is also a challenge. Research is being conducted for the possible use of seawater, or perhaps no water, for fracturing.

Most people don't associate Saudi Aramco with deepwater exploration. However, in the past few years we've completed seismic surveys in the Red Sea and are now drilling the first deepwater prospects.

Not unlike the Brazilian offshore, our prospects also lie below a thick salt section.

We're adopting an integrated exploration approach incorporating 3D full azimuth seismic along with the electromagnetic and high-precision gravity in order to better define the substructure. Our in-house research on multi-geophysics technology with emphasis on joint inversion has substantially improved subsalt imaging in this complex environment.

I think our discussion would be incomplete without addressing our efforts in the environmental front. As part of our environmental stewardship, we are establishing an environmental center in collaboration with KAUST to conduct research related to the marine environment of the Red Sea.

Another example is the offshore Manifa Development which is in a very shallow and environmentally sensitive bay. Manifa, which was put onstream just few weeks ago, is expected to reach half a million BPD by midyear, eventually reaching 900 thousand BPD by the end of next year.

One of its main features is a unique causeway which is 41 km long with 27 drilling islands.

We collaborated with both local and international academic institutions to optimize the design of the Manifa Causeway.

The Arabian Gulf was studied, taking into account numerous environmental considerations to minimize traffic in shallow waters and allow natural marine growth. The design mapped and considered coral reef formations and the habitats of marine life.

> The Arabian Gulf was studied, taking into account numerous environmental considerations to minimize traffic in shallow waters and allow natural marine growth.

Now let me shed some light on what we are doing to realize our technology targets. We believe achieving our research and technology goals requires expansion and interaction with the best talent worldwide. Through our subsidiaries, we're establishing Upstream Global Research Centers in strategic locations, while maintaining core research in Dhahran.

The objective of these centers is to leverage international scientific expertise, have better access to technology, and to strengthen collaboration with industry and academia.

I'm pleased to tell you that our largest international research center will be here in Houston.

A second North American center will be located in Cambridge, Massachusetts, focusing on computational modeling and nanotechnology research.

Both these centers will be operational by the third quarter of this year.

In Europe, two research and technology centers are up and running – TU Delft in the Netherlands, focused on geophysics research; and a technology office in Aberdeen, Scotland, focused on drilling and production technologies.

In Asia, another upstream research center is planned in Beijing.

These centers are part of a larger portfolio for Saudi Aramco. I want to mention that we are opening or have opened new global research centers focusing on downstream in Detroit, Paris, and Daejeon, Korea.

This ambitious technology agenda requires substantial resources in manpower and funding. As we grow, by 2020, we expect to increase our research funding fivefold. We're committed to tripling our manpower in science and technology, with no less than 80% of our research personnel at our headquarters in Dhahran. We also have to account for our generational turnover, or the "Great Crew Change".

We're investing substantially in training and development for young men and women.

It's a massive undertaking to transfer knowledge to this young workforce and especially to compensate for the experience gap

Also, we have many coming from academia to the professional world. This is a bridge that needs to be crossed. Towards this we have established the Upstream Development Center. This center creates a dynamic

> “The center has two main objectives; the first is to compress the onboarding cycle to two years from the typical three-to-four years through tailored courses and hands-on training.”

learning environment for petroleum engineers and geoscientists. The center has two main objectives; the first is to compress the onboarding cycle to two years from the typical three-to-four years through tailored courses and hands-on training.

The second objective of the center is that it will require engineers and geoscientists not only to have functional expertise, but to be more multidisciplinary, so as they will be better able to understand and communicate one another's challenges to be able to develop more creative solutions.

Now, our resources are not unlimited. So when we cannot go alone, we need to collaborate and team with others. We work with academia, the major upstream technology providers and many others in industry – both locally and globally, addressing technical challenges.

We also seek to engender the local research and technology ecosystem within the Kingdom. Saudi Aramco's role in this is to engage on all fronts and act as an “engine room”.

One of our key objectives is to promote research in the Kingdom and leverage R&D success into new business opportunities for Saudi entrepreneurs.

Let me mention the newly created Dhahran Techno-Valley, the research park of King Fahd University of Petroleum & Minerals - located adjacent to Saudi Aramco's main office.

Some of the major oil field service companies renowned for their R&D abilities are already established, or are building new facilities in this Science Park. These include Schlumberger, Baker Hughes, GE, Halliburton, Yokogawa, Honeywell, Weatherford, ARGAS and many others.

Being located in the park has many benefits. The park environment stimulates cross-fertilization of ideas. And technology can be commercialized as new ideas can easily be deployed.

Before I conclude, I'd like to tell you about two new subsidiaries we've created:

The first is the Saudi Aramco Entrepreneurship Center which works to finance and incubate new businesses in Saudi Arabia.

The second is Saudi Aramco Energy Ventures which

> We're confident of a bright future and we offer great opportunities to share our prosperity with thousands of dynamic and motivated industry and academic professionals such as you!

makes global investments in start-up, high-growth companies that offer new upstream and downstream technologies.

Ladies and gentlemen, tens of thousands of energy industry professionals gather each year for this remarkable conference. The reason that you and I, and thousands of others take part in OTC, is that the conference fosters the right combination of competition and collaboration.

We all compete to recruit top talent, new customers, and expand our products and services. But we also collaborate. That's what makes OTC such a rich and rewarding experience.

It's been my pleasure to share Saudi Aramco's Upstream Technology agenda.

Our strategy has a long-term outlook, seeking to develop high-impact technologies addressing the challenges we face. We are enabling this through substantial internal growth augmented by the establishment of external global research centers, while working to foster a broad research and technology environment within the Kingdom.

We're confident of a bright future and we offer great opportunities to share our prosperity with thousands of dynamic and motivated industry and academic professionals such as you!

KFUPM Entrepreneurship Incubator Launched

DHAHRAN, 25 July 2013 – On July 18, Saudi Aramco launched the company's Innovation and Entrepreneurship Incubator inside the King Fahd University of Petroleum and Minerals (KFUPM) campus in Dhahran, which is considered the first distinguished business incubator to be established by Saudi Aramco Entrepreneurship Center. The center is also known as Wa'ed, the Arabic word for "promising".

The Entrepreneurship Incubator plans on becoming one of the best business incubators in the Kingdom through programs to support companies established by young entrepreneurs through consultation, training and financial support.

Simultaneously, Saudi Aramco also launched a pilot program in cooperation with KFUPM to help student entrepreneurs with innovative projects become successful business entrepreneurs. The program is expected to expand later to support the students at other colleges in the Kingdom.

Khalid Al-Falih, president and CEO, and Dr. Khalid Al-Sultan, KFUPM Rector, launched the incubator.

"This project comes within the framework of Saudi Aramco's efforts through Wa'ed to provide young Saudis with more opportunities to introduce their ideas to the world of business and help them prove their competency and capabilities in managing profitable small enterprises that lead to employing other Saudis," Al-Falih said in the inauguration ceremony. "Therefore, we contribute, on one hand, to unleashing the energy and capabilities of our youths, and on the other hand helping others by providing rewarding job opportunities for our youths."

"Saudi Aramco's incubator will supervise several joint cooperative training sessions, first for KFUPM's students and later for other colleges' outstanding students," Al-Falih added. "Distinguished businesses and their successful companies will be supported by continuous supervision, training, technical, financial and legal consultation provided by Wa'ed through experts in these fields, which will be culminated by financial support for economically feasible distinguished ideas."

Al-Falih said the incubator will provide opportunities for ambitious young Saudis to move from being job seekers to employers. A move such as this will further enhance Saudi Aramco's strides toward fostering a thriving knowledge economy.

The CEO indicated that small enterprise sectors are extremely important in most world economies, whether

"Saudi Aramco's incubator will supervise several joint cooperative training sessions, first for KFUPM's students and later for other colleges' outstanding students."

in terms of gross national product or per capital income levels. "Most major countries have only achieved their economic renaissance by relying on small, innovative enterprises," he said.

Al-Falih expressed pride that Saudi Aramco's commitment to community has not come overnight. Instead, it grows from a deep-rooted belief from the company's founding, and it represents one of the company's basic values, as manifested here by the establishment of the Wa'ed Entrepreneurship Center with its major goal of developing and encouraging young men and women in the creation of innovative business. The incubator will support these young entrepreneurs financially and technically as they establish small- and medium-sized enterprises that meet the needs of domestic and regional markets and that create high-quality, sustainable job opportunities for future generations.

"In the strong presence of KFUPM's promising students' innovations, which are notable for being diversified and suitable to become productive investments and boost the Kingdom's economy, comes this initiative from Wa'ed and KFUPM, within the framework of a joint project to sponsor creative innovative ideas to achieve the targeted goals by incorporating entrepreneurship into KFUPM educational curriculum list," Al-Sultan said.

Since its establishment in 2011, Wa'ed has trained 1,000 male and female young Saudis to develop business plans for their projects; provided technical, financial and legal consultation through several programs; and has signed financial deals worth SR 43 million with several of Wa'ed's trained distinctive entrepreneurs to establish 14 firms.

Wa'ed has recently adopted an ambitious plan to support and fund 250 small and medium-size enterprises (SMEs) worth SR 1 billion in five years, and creating thousands of jobs for Saudis by supporting young entrepreneurs and SMEs through loans or partnership.

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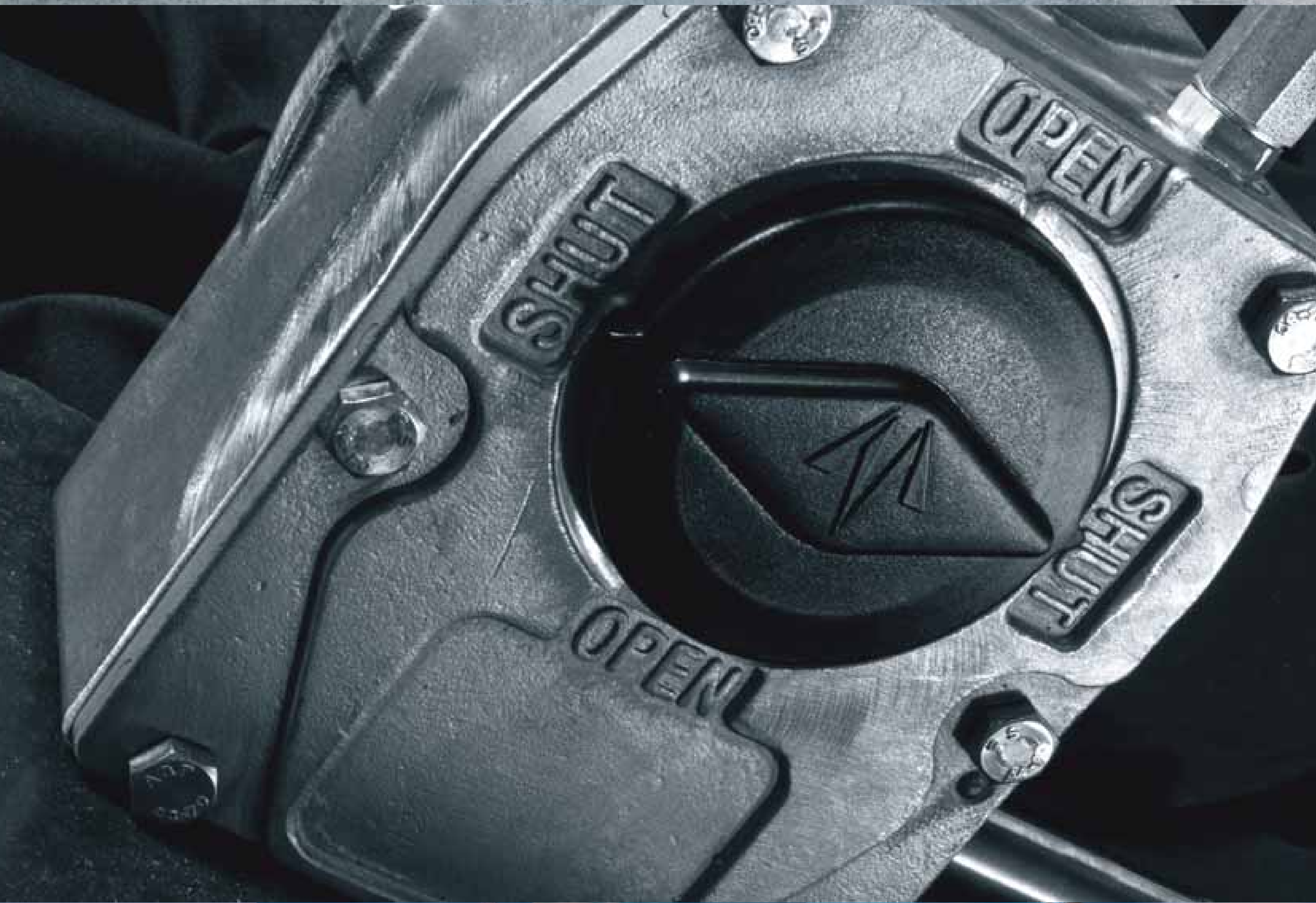

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SPE Saudi Arabia Section 2013 Annual Technical Symposium and Exhibition Review

Committee Members of the 2013 Annual Technical Symposium & Exhibition.

Under the Diamond sponsorship of Saudi Aramco, and with the attendance of Upstream Senior Vice President Mr Amin H. Nasser, and the participation of over 1,500 engineers and earth scientists, the SPE Saudi Arabia Section 2013 Annual Technical Symposium and Exhibition took place from 19–22 May 2013 at the Le Meridien, Al-Khobar, where over 80 technical papers were presented addressing the latest industry technology developments.

Mr Khalid A. Al-Buraik, Vice President of Petroleum Engineering & Development, Chairman of the Board of Directors of SPE Saudi Arabia Section, highlighted the impetus behind the symposium is to provide a platform for knowledge transfer and experience sharing between industry professionals and to promote the latest research and technology developments to address the industry's future challenges. The symposium saw heavy participation by Saudi Aramco professionals, across all upstream specialties, showcasing Saudi Aramco's leading role in innovation and technology development in the industry. Furthermore, Mr Al-Buraik added, "The oil and gas industry is uniquely positioned to capitalize on the strength of its human capital and financial resources to address future upstream challenges for a brighter tomorrow."

Knowledge Sharing and Technology Development

Three distinguished keynote speakers addressed the delegates at the opening ceremony of the 2013 Annual

Mr Amin Nasser cuts the ribbon at the opening ceremony, with (to his right) Mr Khalid Buraik and (to his left) Mr Egbert Imomoh.

Above and opposite: Dignitaries from ATS&E tour the Exhibition.

Technical Symposium and Exhibition, addressing issues of strategic importance to the industry. Mr Khalid Mugharbel, President of Schlumberger Middle East Area, emphasized the importance of developing and maintaining strong partnerships between operators and service providers to ensure development of technologies targeted at solving each operator's unique challenges. Mr David Hobbs, Head of Research at King Abdullah Petroleum Studies and Research Center, focused on the main levers behind the success of unconventional resource development globally and how such practices are implemented in the Middle East.

The series of keynote speeches was rounded off with Mr Egbert Imomoh, 2013 President of SPE International, when he praised the high level of activities of the SPE Saudi Arabia Section in promoting technical exchange and knowledge sharing between its members and the wider community and growing the section's membership to become the second largest in the world, thanks to Saudi Aramco's strong support for all of the section's initiatives. Mr Imomoh also highlighted the section's efforts in bridging the knowledge gap between the industry's young, energetic talent and its experienced professionals.

Technical Sessions and Associated Exhibition

The ensuing three days of the symposium saw a heavy presence and participation from Saudi Aramco in all of the event's 20 technical sessions, addressing various upstream disciplines. The symposium also hosted a notable panel discussion composed of industry technology leaders. The panel was moderated by Mr Waleed Mulhim, Manager of Saudi Aramco's Southern Area Reservoir Management Department, and included Mr Samer Ashgar, Manager of EXPEC Advanced Research Center at Saudi Aramco, Mr Rustom Mody, Vice President of Technology at Baker

Hughes, Dr Greg Powers, Vice President of Technology at Halliburton, and Mr Tom Tilton, Weatherford's Vice President of Research and Engineering and CTO. The panel attracted heavy attendance and an engaging discussion on key issues and opportunities relating to innovation and technology development in the oil and gas industry. The symposium's associated exhibition showcased the latest in technology developments and attracted a large number of visitors.

The symposium also incorporated three pre-event one-day courses addressing; Unconventional Gas Resources Development, Enhanced Oil Recovery, and Underbalanced Drilling Applications. The courses were characterized by heavy attendance and dynamic discussions between the participants and instructors.

In his welcome note, the Chairman of the 2013 Annual Technical Symposium and Exhibition, Mr Ali Habbtar, highlighted the leading role the symposium plays in promoting innovation and technology development in the region for a brighter future, and the outstanding quality of the technical papers and presentations given in the symposium year after year. The event is supported in full through sponsorships and did not require any registration fees.

The ATS&E has taken center stage as the premier gathering of upstream professionals in the region. Since its inception the Symposium has served as a platform for knowledge transfer and experience sharing in the Gulf region, serving the men and women that power the energy hub of the world.

The ATS&E is the section's largest activity and is central to the section's mission of providing a means to disseminate and facilitate the exchange of technical knowledge for the development of oil and gas resources.

Above and below: Dignitaries from ATS&E tour the Exhibition.

Keynote Speakers

Khalid Mugharbel.

David Hobbs.

Egbert Imomoh.

The symposium continued the tradition of putting together an impressive technical program consisting of three pre-event courses, 20 technical sessions, and a high-profile panel discussion. The exhibition attracted 17 exhibitors, seven of which were new to the ATS&E and brought forward new technologies and services that enriched the exhibition and benefited its attendees. The symposium continues to be recognized by SPE International as the event was listed in their Meetings' Calendar. The symposium also applied the strict "no paper, no podium" policy to ensure the level and quality of participation remains high.

The symposium enjoyed a high level of participation throughout its activities with excellent organization by the responsible committees. The theme of the symposium, "The Upstream Innovation Spark, Lighting Our Way to a Better Tomorrow", shines the spotlight on one of the main factors for our industry's continued success, the innovation brought forth by the talented and dedicated professionals of our industry. Such innovations, driven by our professionals and proliferated by events such as the Annual Technical Symposium & Exhibition, will continue to place oil and gas as the energy resources of choice for the world.

2013 ATS&E Keynote Speakers and Opening Ceremony

The 2013 ATS&E opening ceremony was attended by over 600 guests from varied professional backgrounds, including operators, service providers, and academics based in the region and internationally. The opening ceremony commenced with welcoming remarks from the symposium's Chairman, after which three distinguished keynote speakers took the stage. The first keynote speech was given by Mr Khalid Mugharbel (President of Schlumberger Middle East Area), followed by Mr David Hobbs (Head of Research at KAPSARC), and lastly Mr Igbert Imomoh (2013 SPE International President).

Keynote Speaker Topics

The keynote speakers addressed the opportunities and challenges relating to innovation and technology development in our rapidly evolving industry. From the implementation of best-in-class technologies and practices from around the globe, to leveraging SPE International's programs and activities, the speakers highlighted the potential for our industry to accelerate the growth of its asset base and maintain its position as the driving force behind the world economy.

Mr Mugharbel highlighted the need to strengthen the partnership between service providers and operators.

Mr Mugharbel highlighted the need to strengthen the partnership between service providers and operators. Building on an existing strong foundation, elevating the relationship between operators and service providers to a seamless partnership will serve to propel the industry forward. Mr Hobbs complemented the earlier talk by looking at the root-cause enabling the innovation and success of unconventional resources development and how such practices can be leveraged in the region. The series of keynote speeches was rounded off by Mr Imomoh highlighting the key role and achievements that SPE Saudi Arabia Section has played in proliferating technology exchange and knowledge transfer and urged all symposium participants to challenge conventional wisdom and implement the ideas and innovations presented in the symposium in their areas.

2013 ATS&E Exhibition

The exhibition floor plan contained various booth sizes to accommodate the venue's available space. Exhibition slot sizes ranged from as large as 5m x 10m to as small as 2.5m x 3m with prices ranging from $6,000 – $1,500 USD. Many exhibitors elected to combine multiple small slots to create a larger booth, where the exhibition held a total of 17 exhibitors showcasing the latest in technology developments and products in their respective

Mr Hobbs looked at the root-cause enabling the innovation and success of unconventional resources development and how such practices can be leveraged in the region.

companies as follows:

1. Weatherford
2. Halliburton
3. Saudi Aramco
4. Schlumberger
5. Baker Hughes
6. Welltec
7. Petrolink
8. AkzoNobel
9. Abdullah Fouad
10. Shoaibi Group
11. TechnoServe
12. ED Projects
13. Rawabi Holding
14. Wild Well Control
15. Dynamic Energy
16. Gotech
17. Naizak

2013 ATS&E Technical Program

The 2013 Technical program comprised 20 technical sessions with over 80 presentation and keynote and invited speakers tackling subjects related to the following 10 major areas:

1. Petrophysics
2. Drilling Operations

Mr Imomoh highlighted the key role and achievements of SPE Saudi Arabia Section in proliferating technology exchange and knowledge transfer.

3. Production Operations
4. Reservoir Engineering
5. Reservoir Characterization
6. Well Completion
7. Reservoir Simulation
8. New Emerging Technologies
9. Enhanced Oil Recovery
10. Stimulation and Productivity Enhancement

In addition to the technical program, a panel discussion with the title "The Upstream Technology Engine, Keeping the Wheels of Innovation Turning" was held. The panel was moderated by Mr Waleed Mulhim (Manager of SRMD, Saudi Aramco) and was composed of industry leaders in the area of innovation and technology development; Mr. Samer Ashgar (Manager of EXPEC ARC, Saudi Aramco), Mr Rustom Mody (VP of Technology, Baker Hughes), Dr Greg Powers (VP of Technology, Halliburton), Mr Tom Tilton (VP of Research and Engineering & CTO, Weatherford). Each panelist gave a 10 minute presentation where they discussed technology innovation in the industry both from a macro and micro point of view, looking at levers of technology innovation and mechanism to enable greater acceleration of technology development. An engaging Q&A session followed the presentations and was focused on challenges such as; the need to grow innovators from within the industry, the mechanisms required to track innovation on a company-level, the practices and culture needed to accelerate technology adoption in the industry, and how to promote innovation from where it is least expected and not only from R&D centers.

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Above: Mohammed Badri, Managing Director, Schlumberger Dhahran Carbonate Research Center.
Below: Mohammed Badri receives his plaque from Ali Habbtar and Deena Khayyal (far right).

Above: Greg Powers, Vice President of Technology, Halliburton
Below: Keynote speaker Tom Tilton, Weatherford's Vice President of Research and Engineering and CTO.

Mr Samer Ashgar, Manager of EXPEC Advanced Research Center at Saudi Aramco.

Above:

Panel discussion, with Mr Waleed Mulhim, Manager of Saudi Aramco's Southern Area Reservoir Management Department, Mr Samer Ashgar, Manager of EXPEC Advanced Resarch Center at Saudi Aramco, Mr Rustom Mody, Vice President of Technology at Baker Hughes, Dr Greg Powers, Vice President of Technology at Halliburton and Mr Tom Tilton, Weatherford's Vice President of Research and Engineering and CTO.


Robert Kuchinski

Opposite top and above: Scenes at the audience Q&A Sessions.
Opposite: Robert Kuchinski is presented with his certificate.

Top and above: Scenes at the audience Q&A Sessions.

Above: Mohammed Al-Huraifi is presented with his certificate.

Characterization of Shale Gas Rocks Using Dielectric Dispersion and Nuclear Magnetic Resonance

By Anas Almarzooq, SPE; Tariq AlGhamdi, SPE, Saudi Aramco; Khaled H.Sassi, SPE; Mohammed Badri, SPE, Schlumberger.

This paper was prepared for presentation at the SPE Saudi Arabia section Annual Technical Symposium and Exhibition held in Khobar, Saudi Arabia, 19–22 May 2013.

Abstract

Shale gas has become a significant resource play in the USA over the past few years, and oil companies are now evaluating the shale gas potential of many sedimentary basins. The successful development of these shale gas systems has led to a strong exploration campaign in Saudi Arabia to investigate its several onshore basins. These “shales” have complex and varying mineralogies and require intensive petrophysical analysis to determine even basic characteristics. The renewed focus on rock sequences has necessitated the development of workflows and methods for characterizing these shale rocks. With the deployment of new methods comes the need for interpretation frameworks to understand properties from diverse measurements. We investigated the use of two techniques, the dielectric dispersion technique and nuclear magnetic resonance (NMR), as potential tools for systematic shale characterization and examined their applicability to reservoir evaluation in shale plays.

Dielectric properties were measured on a suite of shale gas rock samples selected from several wells across the Silurian source rock formation. The frequency range of 10 MHz to 1 GHz covers the different polarization types of the electric field within the rock samples. The dependence of minerals in the shale-gas rocks on the interpretation of the dielectric response was studied. The dual-range Fourier transform infrared (FTIR) technique was used to accurately quantify the mineralogical composition of the studied samples, including pyrite. Pyrite has an obvious effect on the dielectric responses, and an accurate estimation of its volume is crucial for an enhanced interpretation of the dielectric response. The dependence of the effective matrix permittivity to the shale-gas minerals was well investigated in this work. A workflow was developed to accurately estimate the effective permittivity of the rock matrix to enhance the estimate of water volume from the dielectric response. The high-resolution retort was also used for the quantification of water content, and the results were compared to the water saturations from dielectric dispersion. NMR T_2 was also measured on the selected shale gas rock samples using very short echo spacing to capture all the inorganic and organic

porosity at the nanometer scale. An accurate estimation of total porosity from NMR and total water content from dielectric dispersion enhances the estimation of the total gas in place of the shale-gas rocks.

Introduction

During the past two decades, there has been a tremendous increase in the development and production of unconventional hydrocarbon reservoirs, especially shale gas plays. Successful development of these shale gas systems in the USA, such as in the Barnett shale in Texas, the Woodford Shale in Oklahoma, and the Fayetteville Shale in Arkansas, have led to a strong exploration campaign in Saudi Arabia. Many companies are actively seeking out new and previously overlooked shale systems for commercial development. However, as these unconventional shale plays are developed, it is becoming increasingly obvious that extrapolation of conventional reservoir development techniques and management to these systems is challenging. These "shales" have complex and varying mineralogies and require intensive petrophysical analysis to determine even basic characteristics.

Extensive shale gas reservoir characterization is essential for accurate estimates of the original gas-in-place (OGIP), the production rates, and the storage capacity of depleted reservoirs. Practices of reservoir characterization typically include laboratory measurements of pore, water, and gas volumes and sorption capacity of selected shale samples. Conventionalmethods of sampling and the measurement of these properties are very limited due to the tight and nano-scale nature of the core samples. Shale gas systems are relatively low porosity and ultra-low permeability, and comprise wide ranges of pore sizes. The latter is associated with the diversity of minerals that make up shale, such as clays, carbonates, and organic material (i.e., kerogen). The complexity in mineral content leads to fundamental questions, and often uncertainties, related to the calculation of the petrophysical properties, the total amounts and spatial distribution of original fluids in the reservoir, their thermodynamic states (i.e., adsorbed or free), and, finally, the mechanisms of their transport under the reservoir conditions. The industry requires developing new techniques that would assist in accurate predictions of the rock and fluid properties; leading to much better description of the reservoir properties of the shale plays. The dielectric dispersion and NMR techniques, along with the dual-range Fourier transform infrared (FTIR) method, are the main focus in this study to evaluate the organic-rich shale formations. The dependence of the dielectric dispersion to the mineralogical composition of the rock was studied in this work, in order to accurately estimate the effective permittivity of the rock matrix, hence, a better estimate of the water saturation from dielectric. The NMR measurements at very short echo spacing were also conducted to capture the micro- and nano- porosities of the rocks in order to accurately estimate the total porosity of the shale gas rocks. New workflows are developed and will be detailed in this paper.

Geographic Context of Saudi Arabia Shale Gas Basin

In Saudi Arabia, exploration and exploitation of organic-rich shales is in its early phase. While gas resources in place could be significant, sweet spots need to be found in which established source rocks can also function as reservoirs. Evaluating these opportunities requires refined and well-established reservoir characterization workflows. One of the major geological petroleum systems in Saudi Arabia is the Paleozoic, with Silurian and other lower Paleozoic source rocks, including the lower source rock, some of which are significantly deep and hot. The shale gas rock is the primary source rock for the vast Paleozoic hydrocarbon resources of Saudi Arabia. The Silurian source rock member consists almost entirely of marine shale.

Dielectric Logging

The new dielectric logging device has been recently introduced to measure the formation dielectric constant and conductivity at multiple frequencies from 20 MHz to 1 GHz (Hizem et al. 2008). This new device features a short, articulated pad, allowing optimal pad contact even in rough boreholes and minimizing environmental effects. Two transmitters and eight receivers are mounted on the pad, in addition to a pair of electric dipoles operating in reflection mode, to measure the mudcake or other material directly in front of the pad. The analysis of the multifrequency dielectric measurements provides information about formation water content, water salinity, and rock texture.

Numerous dielectric forward models have been developed and used in our work to convert the dielectric measurements into water saturation, water salinity and rock matrix.The models are so-called bimodal, Stroud-Milton-De (SMD), shaly sand, and complex refractive index model (CRIM) (Stroud et al. 2006; Feng and Sen. 1985; Seleznev et al. 2006; Pirrone et al. 2011). Each type of model has inherent strengths and weaknesses based on the assumptions intrinsic to the model. Some model types (e.g., effective medium and phenomenological) work well with different rock types,

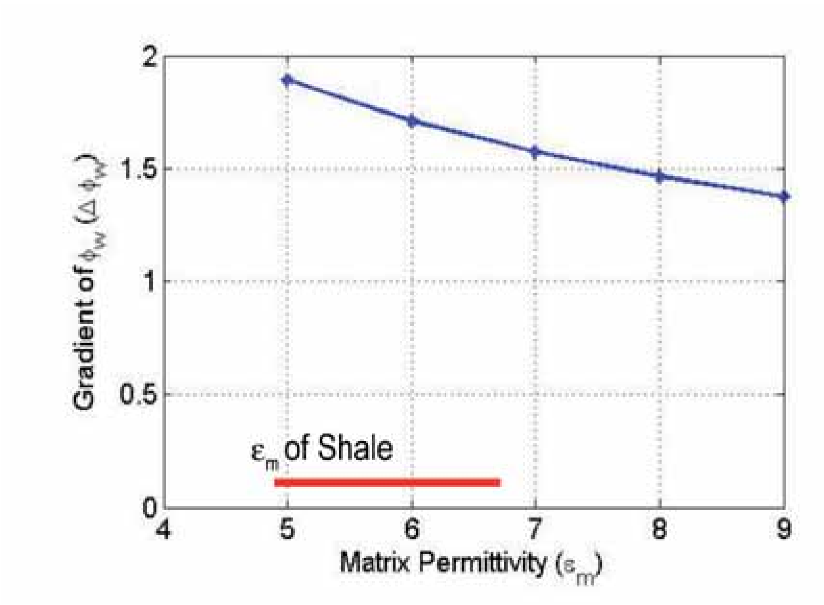

Fig. 1 – Sensitivity analysis showing the error propagation of the matrix permittivity into water-filled porosity for a given rock property.

taking into account the order and shape of replacement material. Other model types (e.g., empirical and semi-empirical) can accurately predict values for the data used to construct them, but are not widely applicable to data sets consisting of different mineralogies, porosities, or water saturations. The CRIM model falls within this latter category, as it does not account for microgeometry of the rock components and does not account for electrochemical interaction between the components. In this study, the bimodal model was used for the processing and interpretation of our dielectric experimental data. It could be summarized by Eq. 1:

$$\emptyset_w = f(\in^*, \in_m, \in_w, \in_h, \emptyset, \text{texture}), \qquad (1)$$

where $\emptyset_w$ is the water volume fraction, $\emptyset$ is the total porosity, and texture represents the grain shape/fraction and the pore structure. $\in^*$ is the measured complex permittivity. $\in_m$, $\in_w$, $\in_h$ are, respectively, the permittivities of the matrix, water and hydrocarbon.

As shown in Eq. 1, the matrix permittivity is a crucial input along with the dielectric measurements to estimate the water- filled porosity. The estimated water volume is strongly dependent on the permittivity of the rock matrix. A sensitivity analysis was performed to show the effect of matrix permittivity on the water-filled porosity of the rock for a given porosity and brine salinity (Fig. 2). The matrix permittivity of shales could vary from 4.9 to 6.8 because of the different mineral types constituting the rock. In contrast to rocks in which few minerals are present, the shale rocks are characterized by the diversity of the mineral types, and each mineral has its own permittivity value. The sensitivity analysis demonstrates that a one-unit error of matrix permittivity (i.e., the difference between $\in_m$= 5 and $\in_m$= 6) could propagate to an approximately 2-p.u. variation of estimated water-filled porosity, a huge error for the low porosity rocks of less than 10 p.u. total porosity.

Therefore, an accurate estimation of the formation water content from dielectric measurements requires accurate inputs of matrix permittivity of the shale rock. A new workflow will be discussed in this study to accurately estimate the water volume fraction of shale gas rocks from the dielectric responses.

Experimental Apparatus of Dielectric Measurements

The laboratory dielectric measuring device used in this study comprises an Agilent network analyzer (NA), ENA series E50771C, controlled using a laptop. The network analyzer is calibrated using a set of short, open, and 50-ohm standards from Agilent. The coaxial probe operates in reflection mode; thus, reflection coefficient S_{11} (scattering parameter) is measured in sequence on the flat ends of the core plug. The measured complex reflection coefficient (S_{11}) are recorded in the form of an amplitude (in decibels) and phase (in degrees) as a function of frequency which was varied from 10 MHz to

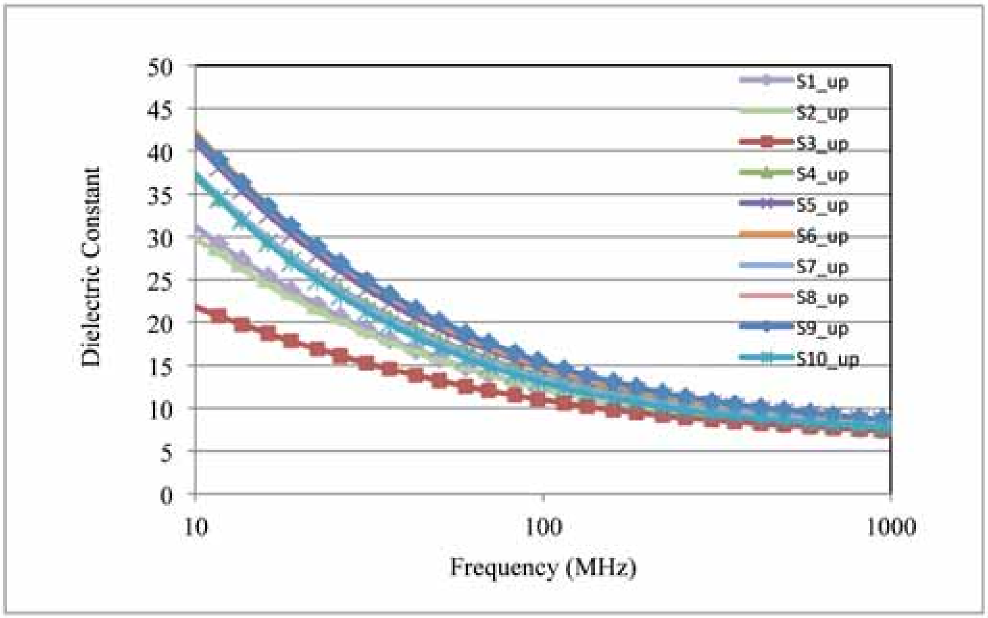

Fig. 2 – Comparison of the dielectric permittivity measured on the upper (up) side of the 10 core samples..

1 GHz, and inverted into conductivity and permittivity, dielectric characteristics of the core sample. The complex dielectric permittivity is commonly expressed as:

$$\epsilon^{*}=\epsilon_{r}+i\frac{\sigma}{\omega\epsilon_{0}}, \quad (2)$$

where ϵ_r is the relative dielectric permittivity or the dielectric constant and is the real part of the complex permittivity. The imaginary part relates to the high-frequency conductivity of the sample (σ), the free-space permittivity (ϵ_0), and the angular frequency (ω). As the frequency of the measurement increases, the term $\sigma/\omega\epsilon_0$ decreases, and the dielectric property ϵ_r starts

Dielectric Laboratory Measurements and Results Discussions

In this study, 10 shale gas core samples from the Qusaiba formation were analyzed. The samples were selected from different wells and at different depths to cover the vertical and azimuth variability of the Qusaiba rock units. From each sample, a plug was drilled, approximately 1.5 in. in diameter. This was ground flat from each end to fit into the flat dielectric coaxial cell. Small pieces were also cut from each sample. These were crushed sufficiently small to remove all the microfractures and coring-induced artifacts, yet large enough to be representative of the rock matrix. The crushed samples were used for the laboratory measurements of the total and effective porosity, LECO TOC, mineralogy analysis, and high-resolution retort for direct quantification of water content. More details of the petrophysical measurements of the crushed samples are given by Handwerger et al. (2011). All laboratory measurements were made on samples in their "as received" state of saturation, meaning that these may not be in their unaltered "native state."

The frequency dependence of permittivity and conductivity (or dispersion) was measured on the 10 selected shale gas core plugs. The measurements were conducted, in sequence, on the ends of each core sample, up and down (dw), as the reflection probe was selected in this study. Measured dielectric-constant values of the upper side of the rock samples are summarized in Fig. 2. The difference of the bulk dielectric constants reflects the complex mixtures of materials and architectures that vary from one rock lithology to the next, although they are from the same formation. The dielectric properties are primarily a function of water saturation, frequency, porosity, and, depending on the rock mineralogy, component geometries and electrochemical interactions. Variations in each of these parameters can significantly change bulk dielectric constants, as can be seen in Fig. 2. The effect of clays is clearly seen in the several samples, and there is some interplay of pyrite and clays. The mineralogy analysis of the studied samples will be detailed later.

The difference in the low-frequency dielectric constants shown in Fig. 3 reflects the difference of mineralogy, lithology, and rock microstructure of the two measured

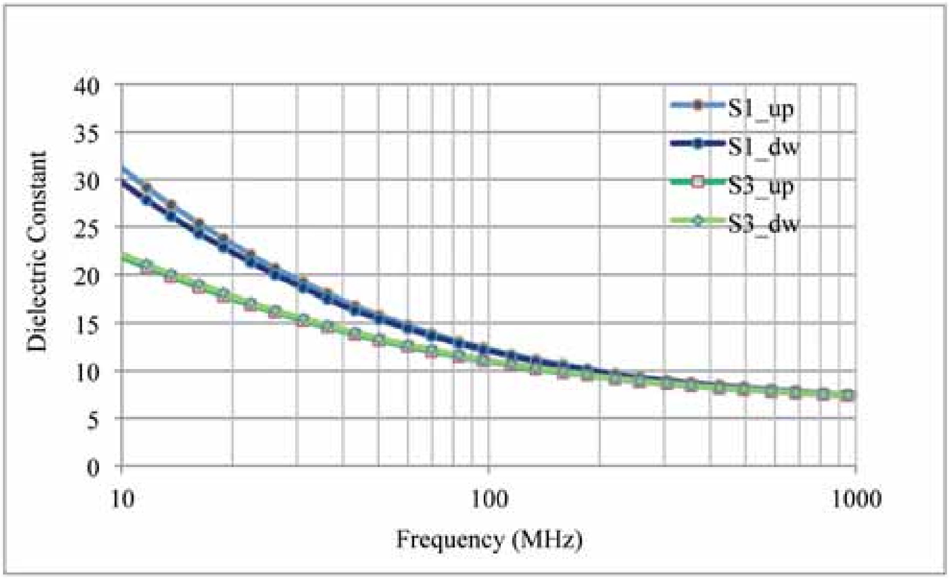

Fig. 3 – Dielectric permittivity measured on the upper (up) and down (dw) sides of each of the two samples 1 and 3.

samples. The overlapping of permittivity at the high-frequency range (1 GHz) indicates similarities of porosity and water content in the two samples.

Therefore, variations in mineralogy, rock microstructure, and water content can significantly change the effective dielectric constants. The dependence of the effective matrix permittivity and the mineralogy of the rock represent one of the main subjects in this study.

The dielectric measurements were inverted to estimate the water-filled porosity for each measured sample. A default value of effective matrix permittivity was applied as the input parameter for the inversion. This study was conducted to intuitively validate the dependence of the water-filled porosity to the matrix permittivity, in addition to the sensitivity analysis detailed above. The estimated water saturations were compared to the saturation measurements from high-resolution retort using the crushed samples. These samples are weighed and placed in a retort oven. They are then heated continuously to a succession of three characteristic retort temperatures. During the retort process, the fluids – free, capillary, and clay- bound – are vaporized, collected, condensed, separated, and measured. Fig. 4 shows an overestimation of the dielectric- derived water saturation compared to the retort saturations. This overestimation of water volume is mainly caused by the random choice of the matrix permittivity. Therefore, an accurate estimation of water content of the shale gas rocks requires a better estimation of the effective matrix permittivity. In the next section, a workflow will be discussed to enhance the estimation of the rock matrix permittivity and demonstrate its dependence to the mineralogical composition.

Effective Matrix Permittivity of Shale Gas Rocks

The effective matrix permittivity of each rock sample was estimated by inverting the measured permittivity and conductivity dispersions. The dielectric physics model used for the inversion is the so-called bimodal model which attributes the dielectric dispersion to rock grains with plate-like shapes. These grain shapes properly describe the dielectric behavior of most rocks, but are even more appropriate for the clay particles, which are plate like and are abundant in the shale samples. The water saturations measured from the high-resolution retort technique was used as input parameter in this inversion process. The workflow applied to estimate the effective matrix permittivity is described in Fig. 5.

Mineralogy Composition

Mineralogy is a fundamental part of formation description. In this study, a quantitative mineral analysis of the selected samples is based upon the Fourier transform infrared (FTIR) spectroscopy measurements with special sample preparation and signal processing steps. The accuracy of the FTIR analysis of natural

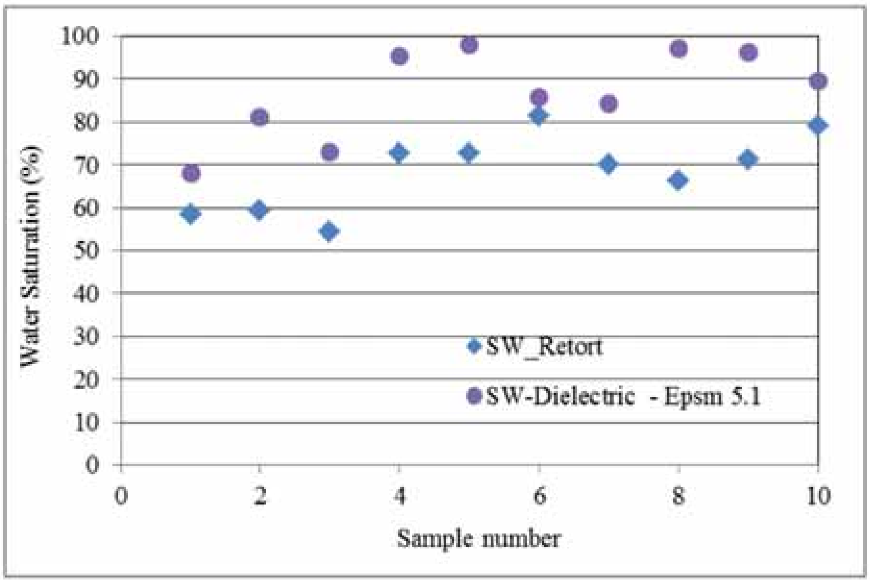

Fig. 4 – Comparison between the saturations measured from retort and those estimated from dielectric measurements using the default matrix permittivity value of 5.1.

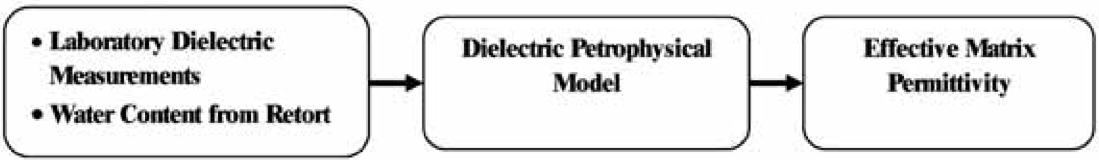

Fig. 5 – Workflow applied to estimate the effective matrix permittivity.

sedimentary materials is difficult to verify; however, other methods, such as X-ray diffraction (XRD), have large relative errors when clay minerals are involved (Herron et al. 1997). Note that FTIR detects total illite and smectite independent of any interstratification. During the course of the FTIR analysis, few characteristics have been noted. Illite is the most commonly observed clay mineral in the samples we studied. It represents almost half the weight percent of the captured minerals. The muscovite concentrations average 40% of illite concentrations. This is a high number. The experiment shows that the FTIR procedure is able to quantitatively distinguish illite from muscovite, even when present in the same sample. This is not likely to be the case for XRD. For clay identification, the < 2-µm fraction, which presumably has excluded any muscovite, is likely to have been overlooked by this common XRD procedure. Kaolinite is also present within the studied samples with an average concentration of 10% that of illite.

Dependence of Matrix Permittivity on Mineralogy Composition

The complex refractive index (CRI) dielectric mixing law is the forward modeling technique that will be used to investigate the dependence of the effective matrix permittivity $\in_{meff}$ on the mineralogy composition of the rock. The CRI law could be expressed as

$$\sqrt{\in_{meff}} = \sum_{i=1}^{n} V_i \sqrt{\in_i} \,. \quad (3)$$

V_i represents the volume fraction of rock minerals, $\in_i$ is the dry matrix permittivity of each mineral, and n is the number of minerals measured by the FTIR system.

A deterministic misfit data approach was developed in this study to investigate the effect of mineralogy composition of the rock on its effective matrix permittivity. This study aims at computing the dry permittivity of each mineral of the selected samples

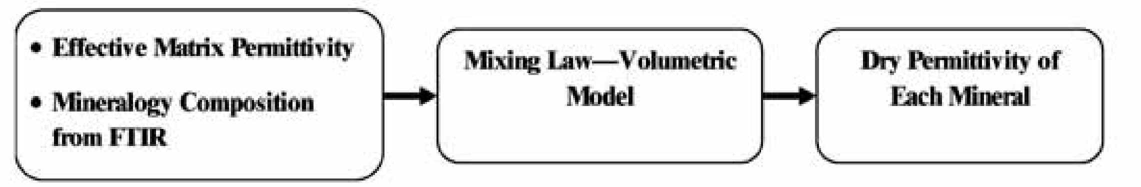

Fig. 6 – Workflow applied to estimate the dry permittivity of minerals.

TABLE 1— PERMITTIVITY VALUES OF KEY MINERALS IN THE STUDIED SAMPLES

Mineral	Permittivity value
Quartz	4.65
Illite	5.8
Kaolinite	5.08
Chlorite	5.02
Muscovite	5.67
Pyrite	37.43

measured by FTIR system. To reconstruct the effective matrix permittivity estimated in the previous section, the least squares technique was used to minimize the distance between the estimated ϵ_{meff} and the computed matrix permittivity value. The mixing law expressed in Eq. 3 is used to predict ϵ_m during the inversion process. The $L2$ norm function that we developed in this study includes a data misfit function and a regularization term. The weight of each function during the inversion process is controlled by the trade-off parameter α. The $L2$-norm regularization part includes a reference dry permittivity value ϵ_{ref} of each mineral. This is used to constrain the unreasonable values and guide the inversion process to achieve reasonable permittivity values of all minerals. The function to be minimized is then expressed by Eq. 4:

$$J = \frac{1}{2}\left\|\sqrt{\epsilon_{meff}} - \sum_{i=1}^{n} V_i\sqrt{\epsilon_i}\right\|^2 + \frac{1}{2}\sum_{i=1}^{n}\alpha_i\left\|\sqrt{\epsilon_i} - \sqrt{\epsilon_{ref}}\right\|^2 \quad (4)$$

The permittivities of selected minerals are measured using a laboratory technique that we developed for powder measurements. These minerals include kaolinite, quartz, smectite, dolomite, and calcite. Therefore, the regularization term becomes dominant while inverting for the permittivities of these minerals. The workflow is shown in Fig. 6.

The dry permittivity values determined from the workflow in Fig. 6 are summarized in Table 1.

Pyrite is a relatively heavy mineral in shale gas rocks. It influences the formation evaluation when it is present at large quantities (Anderson et al. 2006; Clennell et al. 2010). Pyrite has an obvious effect on the dielectric responses, enhancing conductivity and permittivity very significantly, in particular in the dry samples. Therefore, an accurate estimation of dry permittivity of pyrite is crucial to account for it in the interpretation of dielectric responses. The analyzed samples contain a broad range of pyrite. The estimation of the dry permittivity of pyrite along with the key shale minerals through the workflow developed above represents a major element in this paper.

The dry permittivity estimated above was used to reconstruct the effective matrix permittivity of the studied shale gas rocks. These were used to redetermine the water saturation from the measured permittivity and

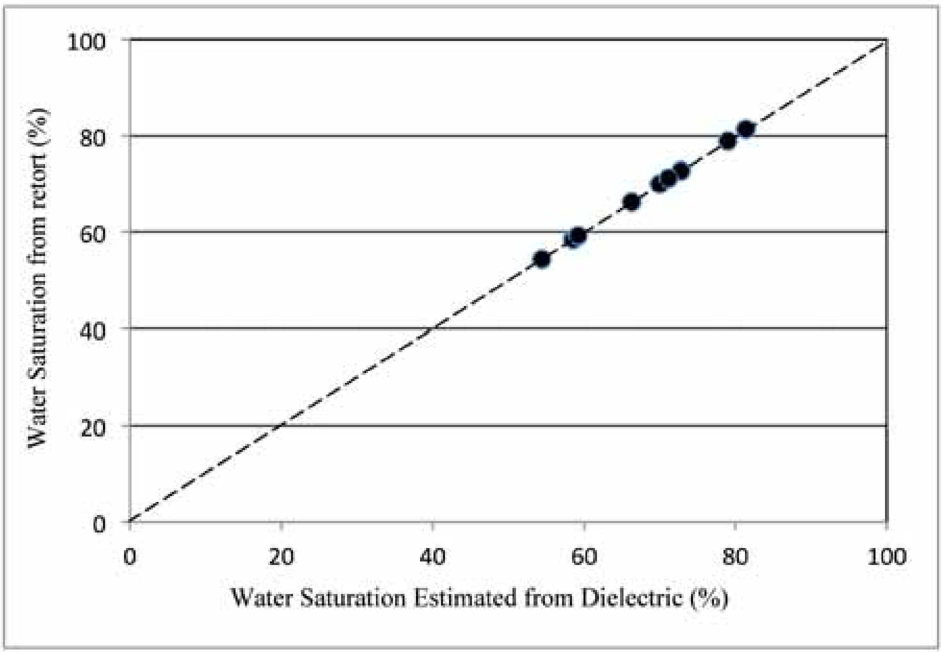

Fig. 7 – Comparison of water saturations from retort and dielectric measurements using the reconstructed permittivity from the workflow.

conductivity dispersions. Fig. 7 shows a good agreement between the water saturations determined from retort and those from dielectric measurements.

Note that water saturation determined from dielectric measurements is the sum of the free (almost absent in these rocks), capillary, and bound clay water and structural water.

NMR Measurements

NMR T_2 relaxation logging has been used regularly in unconventional reservoirs to measure total porosity and bound fluid volume (Hook et al. 2011; Curtis et al. 2010). In this study, we analyzed the T_2 responses through the laboratory measurements on the selected shale samples. The NMR measurements were conducted in the laboratory at 2-MHz frequency. A wide range of echo spacing (echo time, TE) in the Carr-Purcell-Meiboom-Gill (CPMG) sequence from 0.106 msec to 0.2 msec was tested to select the most appropriate for the studied core samples. The 0.130-msec echo spacing was selected for proper characterization of shale samples with pore sizes at the nanometer scale. The NMR T_2 distribution measured on one of the selected samples is shown in Fig. 8. The NMR signal shows a unimodal pore-body size distribution with most of the T_2 signal in the range of 0.1 to 1.0 msec. Most of the signal falls below 3 ms, reflecting porosity and residual water saturation variation.

A small piece was cut from the same sample studied above and used confocal microscopy. The confocal image was processed to map the microporosity. The confocal microscopy result is shown in Fig. 9. The analysis shows the most abundant pore-body size is in the range of 0.2 to 0.3 µm in diameter, which agrees with the unimodal pore size from NMR T_2.σ

An accurate estimation of porosity from NMR requires shorter echo spacing due to the fast relaxation time of clay-bound water. Being sensitive to the hydrogen of the fluid within the rock, NMR porosity measures the total fluid of the “as-received” shale sample. The combination of the NMR technique with the accurate water saturation from dielectric measurements allows enhancing the estimation of total gas in place.

Conclusions

The dependence of correct identification of minerals in shale gas rocks on the interpretation of the dielectric response was studied in this paper. The dual-range FTIR technique was used to accurately quantify the mineralogical composition of the studied samples, including the pyrite. The pyrite has an obvious effect on the dielectric responses, and an accurate estimation of its volume is crucial for an enhanced interpretation of the dielectric response. The dependence of the effective matrix permittivity to the shale gas minerals was well investigated in this work. A workflow was developed to

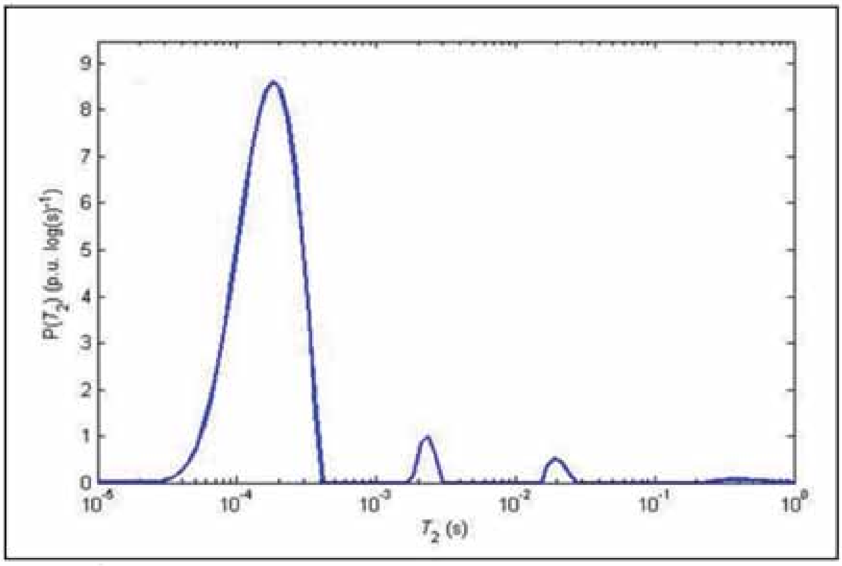

Fig. 8 – The NMR T2 distribution of the shale gas measured sample.

accurately estimate the effective permittivity of the rock matrix to enhance the estimate of water volume from the dielectric response. NMR T_2 was also measured on the selected shale gas samples using very short echo spacing to capture all the inorganic and organic porosity at the nanometer scale. An accurate estimation of total porosity from NMR and total water content from dielectric response enhance the estimation of the gas in place of the shale gas rocks.

Acknowledgment

The authors are grateful to Saudi Aramco and Schlumberger for the permission to publish this paper. We would also like to express our deep appreciation to the RDD team of Saudi Aramco for the extensive discussion on the shale gas subject. Chuks Chimezie from TerraTek helped with the retort measurements, and Neil Hurley helped with the confocal image.

Nomenclature

$\emptyset$ = Total porosity of the rock
$\emptyset w$ = Porosity filled by brine
$\in_r$ = Relative dielectric permittivity of the rock
$\in^*$ = Effective complex permittivity of the rock
$\in_{meff}$ = Effective permittivity of matrix grain
$\in_w$ = Complex permittivity of the brine
$\in_h$ = Permittivity of the hydrocarbon (gas in this paper)
$\in_0$ = Free-space permittivity
σ = Conductivity of the rock (S/m)
ω = Angular frequency

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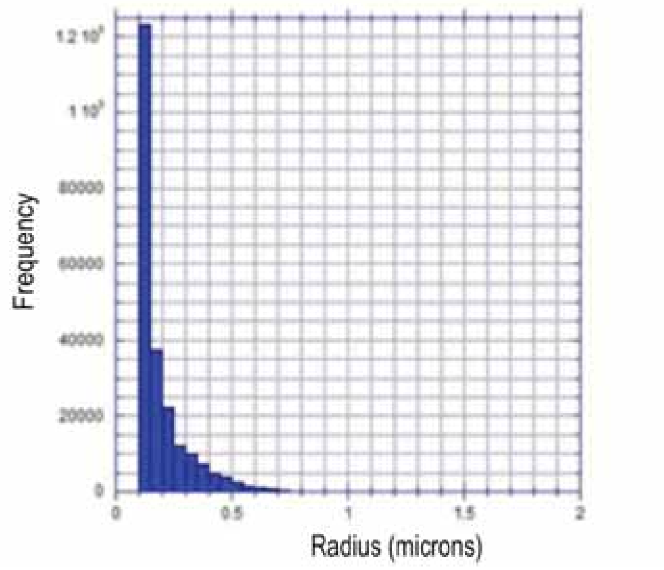

Fig. 9 – Frequency histogram of pore-body radius based on results from confocal microscopy.

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Frequency Dependent Magnetic Resonance Response of Heavy Crude Oils: Methods and Applications

By Arjun Kurup, Andrea Valori, H. Nate Bachman, Schlumberger Dhahran Carbonate Research, Jean-Pierre Korb, Ecole Polytechnique, Martin Hürlimann, Schlumberger Doll-Research, Lukasz Zielinski, Houston Formation Evaluation.

Abstract

Oilfield nuclear magnetic resonance (NMR) applications are widely accepted for characterizing reservoir rocks and fluids. All of the downhole applications, and most oilfield NMR lab work, are carried out assuming that the results are independent of the operating frequency. The assumption is generally warranted, since most NMR logging tools and lab devices operate in the 0.5 to 2 MHz range. However, two strong motivations exist for investigating the frequency dependence (that is, dispersion) of NMR of crude oil samples: 1) introduction and acceptance of lower frequency logging while drilling (LWD) and multifrequency wireline NMR tools, and 2) sensitivity of NMR dispersion to the interaction and dynamics of molecules of varying size in complex fluids.

We report here on a versatile frequency-dependent lab NMR measurement known as fast field cycling (FFC) NMR. The results clearly demonstrate a frequency dependence of the longitudinal relaxation time, T_1, for crude oils between 10 kHz and 40 MHz. The study investigates the full T_1 distributions for crude oils containing significant amounts of all the SARA (saturates, aromatics, resins, asphaltene) fractions, including a broad range of concentrations for the heavier fractions. For crude oils containing minimal asphaltene and resin fractions, the dispersion is minimal. In contrast, crude oils containing larger concentrations of asphaltene and resins show a clear shift of the T_1 distribution to longer times at higher frequencies.

We will discuss the implications and benefits of NMR dispersion for oilfield application. We suggest how the dispersion can be understood in terms of the molecular dynamics of asphaltenes with the rest the oil. Finally, we will provide an overview of the experimental challenges in making these measurements, including the hardware design and the specialized pulse sequences required for acquiring multi-frequency data.

Fluid Identification in Complex Clastic Reservoirs Using 2D NMR Maps: A Case Study from Saudi Arabia

By Yacine Meridji and Gabor Hursan, Saudi Aramco; Mahmoud Eid and Ron Balliet, Halliburton.

Abstract

The formation evaluation of Saudi Arabian reservoirs presents multiple challenges. The complexities encountered include varying mineralogy and mixed lithologies, a wide range of porosities and pore types, hydrocarbon viscosity, and variable formation water salinities.

Two-dimensional (2D) analysis of NMR data acquired with simultaneous T_1-T_2 has proven to be beneficial for the identification and quantification of hydrocarbon-bearing reservoirs and providing valuable information about porosity and reservoir quality.

NMR porosity measurements are free from mineralogical effects and, therefore, provide a very good estimate of formation porosity. Moveable and bound fractional fluid porosities from NMR provide additional reservoir information and are used for estimating permeability. Simultaneous T_1-T_2 acquisition and two dimensional analyses provide graphic 2D identification for the presence of hydrocarbons and hydrocarbon type, as well as a volumetric estimate of near wellbore hydrocarbons independent of formation water resistivity.

Results from a simultaneous NMR T_1-T_2 acquisition are compared to formation tester results. The strong correlation between the NMR predictions and the formation tester results suggests this method is effective in the evaluation of challenging formations and might also be applicable to other reservoirs.

Integrated Reservoir Management Approach to Improve Injection Efficiency in a Low Transmissibility Sector of a Giant Carbonate Reservoir

By Lajos Benedek, Muhammad Almajid, and Ahmed H. Alhuthali, Saudi Aramco.

This paper was prepared for presentation at the 2013 SPE Saudi Arabia Section Technical Symposium and Exhibition held in AlKhobar, Saudi Arabia, 19 - 22 May 2012.

Abstract

This paper provides a critical review of the integrated reservoir management process implemented to maximize ultimate recovery by maintaining an optimum reservoir pressure distribution in a low transmissibility sector of a giant carbonate reservoir. The peripheral water injection is the main driving mechanism in this reservoir due to the excellent areal transmissibility from the flanks towards the center of the reservoir. However, the study area is limited and characterized by a various degree of low transmissibility due to the degradation in reservoir quality and the presence of a tar mat at the flanks. The main challenge is to provide an adequate pressure support far away from the peripheral injection line and to sustain the required production capacity from the study area. Conventional peripheral water-flooding is insufficient to meet the ever increasing production capacity without an optimized injection set-up consisting of up-dip and down-dip peripheral injectors.

The study demonstrates that cohesive understanding of the flow mechanism, which entails integration of various sources of information, is crucial to achieve successful pressure maintenance and voidage replacement schemes. Consequently, detailed characterization of the tar region was constructed through multiple realizations covering the entire spectrum of uncertainties and impacts on reservoir performance. The injection efficiency over various production scenarios was also carried out using finite-difference and streamline tracing to capture the interaction between producers and injectors. In addition, a coupled subsurface-surface integrated modeling was utilized to identify bottle-necks and evaluate development options.

Production performance and acquired reservoir surveillance data vindicated the implemented practices. Optimum reservoir pressure distribution was observed over the entire study area. Conventional and advanced open-hole log results from strategically placed evaluation wells and time lapses of saturation logs from key monitoring wells over a 5 years period indicated favorable areal and vertical sweep efficiency.

Fit for Purpose Underbalanced Coil Tubing Surface Equipment Permits Safe Drilling of High H_2S Horizontal Gas Wells in Saudi Arabia with Higher Productivity Results

By Shaker Khamees,Mohammed Ali, Saudi Aramco; Ayman Marey and Juan C. Valecillos, Weatherford International.

Abstract

This paper describes the underbalanced drilling (UBD) surface package used in the Saudi Aramco underbalanced coiled tubing drilling (UBCTD) project. A brief description on each item of this equipment is presented, as well as a description of the overall process flow. Moreover, the evolution and modification of the package throughout the period of the project and the optimization of the equipment to meet new challenges and to overcome some drilling hazards, such as erosion and high H_2S levels, is discussed.

The objective of the project is to drill reentry horizontal lateral sections in a hole size of 3⅝" with coil tubing (CT) using the UBD technique specifically the "Flow drilling" technique to increase the hydrocarbon's productivity without damaging the formation, increasing the rate of penetration (ROP) and eliminating risk of losses or wellbore instability.

The UBD surface equipment used for the UBCTD project was designed to handle maximum allowable rates to drill the well within safe limits. The equipment were selected and designed on the basis of historical data gathered from offset wells in the same specific field.

The main focus in this paper will be on the lessons learned throughout the period of the project regarding the UBD surface equipment, which was specially built for this project.

Core Acquisition from a New Sidewall Rotary Coring Tool: Overview and Experience from Saudi Arabia

By Aamir Siddiqui, Wafi Al-Algam, Ivo Nuic, Baker Hughes.

Abstract

Detailed reservoir characterization is the main objective of all petrophysical measurements. The information obtained from petrophysical logs and well testing measurements is integrated with core-based sedimentological studies and core analysis measurements. Core-based information is crucial in the exploration phase of a field because it enables an extensive understanding of the reservoir rock potential. To reduce the operational time and cost, conventional full-core acquisition programs are often curtailed and operators rely on sidewall coring. Rotary sidewall cores provide accurate depth-controlled core plugs in various lithologies in a quicker and cost-effective way.

A new rotary sidewall coring tool has been utilized in Saudi Arabia that enables recovery of high-quality core plugs even from small-sized boreholes. The acquired core plugs have sufficient size for use in conventional and special core analysis, and petrographic studies. The capability to recover up to 60 samples in a single trip enables good coverage of the different lithologies during one acquisition. The core acquisition time per sample is significantly improved over previous generation tools, thus enabling a significant reduction in coring operation time. In addition, the ability to obtain 60 samples in one run enables operators to modify their core-acquisition programs, as sidewall cores provide a good alternative if conventional core programs are not properly executed.

This paper reviews experience and examples where rotary sidewall cores were obtained from several clastic and carbonate formations from different fields in various locations within Saudi Arabia. The operational environments and borehole conditions in which sidewall cores were obtained were exceedingly heterogeneous. These cases include very hard sandstones, mixed sand and shale layers, and limestone to dolomitic carbonates.

Dead Horizontal Well Revival Utilizing Fiber Optic Enabled Coiled Tubing Combined with Underbalance Perforating Gun Deployment Technique (Case Study)

By Fehead M. Al-Subaie, Nashi M. Al-Otaibi, Fouad Al-Sultan, Anton Burov and Azwan H. Keong.

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Abstract

In many oil fields water production often threatens the reservoir performance and economic viability of wells. Excess unwanted water production can cause an increase in production costs and a decrease in productivity. To mitigate this, it is crucial to utilize water management techniques to reduce water cut, optimize oil production, extend the well life and recover idle wells.

The most effective technique for water shut-off (WSO) treatments in Saudi Arabia comparatively to the costly workover rig treatments was proven to be a rigless WSO using mechanical isolation, especially when it gives options to perform additional operations with the single rigup.

This article describes the first time – in Saudi Arabia – of the implementation of the mechanical rigless WSO method, used to mechanically isolate a watered open hole section. This isolation is accomplished by utilizing fiber optic enabled coiled tubing (FOECT) telemetry and then setting an inflatable packer in the liner. It is capped with cement following perforation treatment, by using a completion insertion and retrieval under pressure (CIRP) deployment system, which allowed the guns to be run and pulled under live well conditions without killing the well.

The depth correlation for the packer setting – and later for perforation depth correlation – was performed by fiber optic bottom-hole assembly (FOBHA). The inflation of the packer and the injection through it were monitored and adjusted in real-time with the FOBHA pressure-temperature casing collar locator (FOBHA-PTC) measurement inside and outside the FOECT string. The FOBHA utilized a deployment method from CIRP technology to perforate the new formation by using the tubing conveyed perforating (TCP) e-Fire firing head under well dynamic underbalanced conditions.

Recent production results showed a previously dead well flowed at 10,000 barrels of oil per day (BOPD) with 12% water cut.

This innovative combination of WSO solution with FOECT and CIRP techniques proved to be an effective method to minimize operational time, equipment and footprint on location, and efficient perforating in a single underbalance run at one rigup.

This article also discusses the challenges faced during job execution, lessons learned, and experience gained to optimize similar jobs in the future.

Introduction

This field has a modest natural water drive support; therefore, peripheral water injection was introduced to provide full pressure support in this field. Initially, water injection was conducted by gravity water injection, but this was replaced later by power water injection to offer flexibility in managing the oil sweep efficiency. The focus of this study is the Arab-D reservoir, which is the most prolific oil bearing formation. In this field, Arab-D is characterized as a folded anticline consisting primary of Jurassic carbonate. The diagenetic processes of the Arab-D sediments are minimal and the calcite cementation is rare and barely coats the grains surface. Overall porosity and permeability averaged 20% and 600 mD, respectively.

It is important to mention that the water management strategies were not at the expense of sweep effectiveness. Areal sweep success can be easily demonstrated by the even movement of the flood front while the vertical sweep can be supported, and the formation analysis logs the results for wells drilled behind the flood front. Understanding the fluid mechanics is the main reason for successful water management strategies in this field. Although viscous forces are high due to high production and injection rates, gravity forces are playing a major role in determining the level of oil sweep. Great areal extent, peripheral water injection, dipping structure, and relative good vertical permeability are the main reasons favoring gravity forces and fluid segregation. Therefore, this field is defined as a gravity dominated system displaying a clear bottom up sweep. This fact makes horizontal drilling in the top of the reservoir and rig-less water shut-off (WSO) viable options in reducing water production.

One of the recent practices in drilling horizontal and multilateral wells to maximize reservoir contact – and carefully placing wellbores in oil zones at a sufficient distance from water injectors or aquifer – can delay water breakthrough. Although these advanced types of completions have proven advantageous in terms of maximizing oil production while managing water encroachment through the formation, water cut can still increase with time and limit well performance.

Water is injected into the field to increase pressure and thereby stimulate production. Over time, the volume of water that is lifted along with the oil increases, therefore the volume of oil declines proportionally until eventually what flows out of the reservoir is almost pure water.

To restore well potential and decrease water production, a secondary water management technique is required through remedial work. The zonal isolation can be done either permanently, by completely shutting off the zone's producing water; or temporarily, by isolating the water-wet intervals, followed by acid stimulation of the oil zones only. These isolations require some chemical and/or mechanical barriers inside the wellbore and/or the reservoir. Failing to have a proper isolation can cause severe problems, from getting higher water cut up to even killing the well.

The mechanical WSO technique is one of the most feasible solutions to reduce water and restore oil production with a rigless application. Applying this technique in horizontal wells requires coil tubing (CT) deployment to reach the target depth, set the packer in the wellbore to isolate water wet zone, pump cement to reinforce the packer (mostly in the field, inflatable packers are normally utilized as a cement retainer and/or a bridge plug to isolate the "undesirable" zone) and lift the well by pumping nitrogen.

In some complex wells when the existing production zone is significantly water wet, the remedial techniques may require us to switch the well to raise the productivity zone after lower water wet zonal isolation. CT can provide additional perforating capability and flexibility. The rigidity and strength of CT allows enduring greater tensile and compressive forces, which is a major operational advantage when perforating in highly deviated and horizontal wells or with longer gun strings. Ideal for live wells; pressure control techniques are used to run long gun strings and either drop off or retrieve the guns without having to kill the well.

To override the damage problem from the remedial WSO cycle, we can use conventional perforating CT to complete the well underbalance. The main advantages of using CT were the ability to displace the wellbore fluid with diesel to create the underbalanced condition and a lower overall cost when compared to perforating using a rig.

Although conventional methods were deemed efficient in this application, concerns included not only technical challenges, such as perforating off depth due to inaccurate depth control, not being able to detect fired guns, and improper balance conditions; but also economic aspects on long operational WSO remedial cycle for the well, resulting in additional costs for the operator.

This article describes the first time in Saudi Arabia's oil field implementation of the combined fiber optic enabled coiled tubing (FOECT) WSO and completion insertion and retrieval under pressure (CIRP) techniques, thereby allowing the operator to get reliable real-time bottom-hole data measurements.

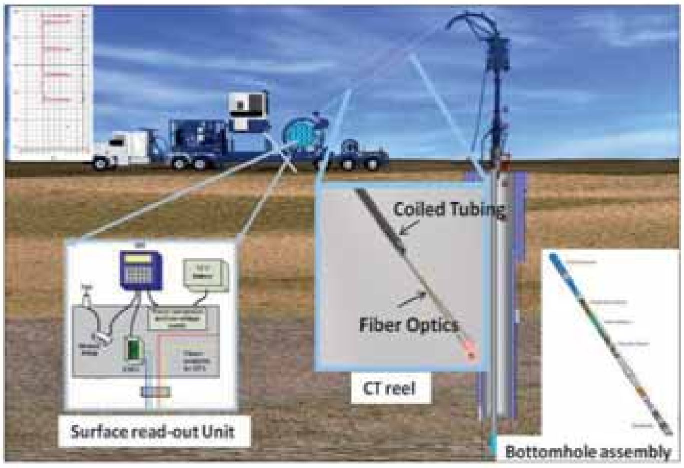


Fig. 1. FOECT

The availability of real-time casing collar locator (CCL), gamma ray (GR), tension-compression (TC) sub, bottom-hole temperature (BHT) and differential pressure readings enable proper packer setting depth, optimization of the cement design, adequate packer inflation and cement injection, respectively, without exceeding the packer limitations for the WSO cycle. FOECT was also allowed to deploy the perforation systems and run all the guns in one run using CIRP as a deployment system, which allowed the guns to be run and pulled under live well conditions without having to kill the well.

The applied techniques optimized the whole WSO and perforation cycles at one rigup that resulted in a higher success rate of WSO treatment.

Background

The success of the WSO depends on the integrity of mechanical isolation (packers) and the treatment fluid placement. Conventional CT WSO jobs are done without adequate control of WSO fluids and mechanical barrier setting. In wells where the water intervals are in the horizontal section, inflatable packer setting often has a high risk of failure due to the lack of downhole parameter control due to excessive washout and the hole's ovality[1]. Conventional CT systems only measure depth with CT length monitoring and the critical bottom-hole information such as pressure and TC are calculated from the surface acquisition data. This lack of exact downhole monitoring and control may lead to unsuccessful treatments.

The FOECT system is a real-time surface readout system of downhole measurements conveyed on CT, Fig. 1. It is composed of fiber optic cables installed inside a CT string, a fiber optic bottom-hole assembly (BHA), surface electronics and software. The system helps improve precision by enabling real-time interpretation of measured downhole data. This innovative technique enhances zonal isolation treatments during the full cycle of design, execution, and evaluation.

Fiber optics are installed in the CT inside a carrier, which is non-intrusive[2]. Therefore, standard operations normally done with conventional strings can be carried out with the FOECT string – including pumping corrosive fluids and dropping balls. During the typical operation of the system, the downhole data are transmitted from the CT working reel via wireless communication to the CT cabin where the monitoring system and specialized software acquire, display, monitor and record real-time job parameters. The surface acquisition system can also communicate with the tool downhole and send commands.

The fiber optic carrier has a 1.8 mm (0.071”) outside diameter (OD), making it non-intrusive to the CT internal diameter (ID). It is very lightweight and equivalent to 1/20th of the weight of an electric wireline cable. The material itself can withstand hostile bottom-hole con- ditions and temperatures up to 300°F[2].

The FOECT system ensures that the WSO fluids only target water intervals, avoiding oil zones. Below are the real-time downhole data measured with the system:

• BHT outside the CT string enables the adjustment of the cement formulation design and any other required WSO fluids.
• Bottom-hole pressure (BHP) inside and outside the CT string, enable proper inflation of the packer and eliminate the risk of exceeding its operating limits during the injection of the WSO fluids.
• CCL and GR, enable accurate setting depth of the inflatable packer.

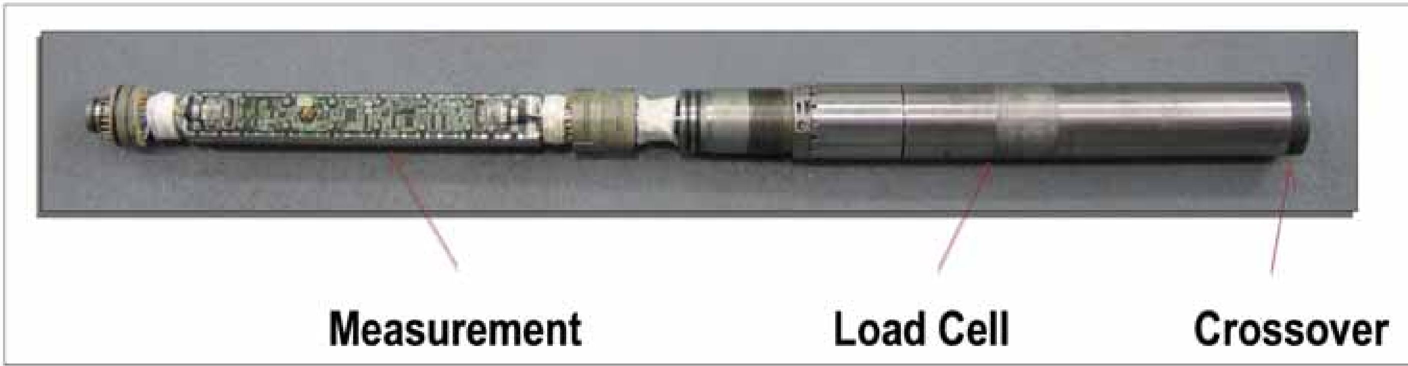


Fig. 2. FOECT tension and compression module.

• Tension and compression forces confirm adequate setting and disconnect of the inflatable packer.

FOECT Tension and Compression Tool

The FOECT tension and compression module, Fig. 2, used on this well is 2⅛" OD and can handle up to 2 bpm pumping rate through it. The tool measures tension, compression and torque loads. This tensile measurement is a critical parameter to monitor during the packer setting and release, to prevent damage to inflatable packers.

CIRP Deployment Blowout Preventer

CIRP is a technique for deploying long gun strings under pressure when the lubricator is shorter than the gun string[3, 4]. It is particularly useful for retrieving long gun strings from a perforated well without killing the well. The three main components of the system are:

1. The CIRP connectors (to connect the gun sections together).
2. The CIRP deployment stack (to operate the well under pressure).
3. Gate valves (barriers to isolate the lubricator from the well pressure).

CIRP Connector

The connector, Fig. 3, is the mechanical and ballistic link between the gun sections in the lubricator. The CIRP lower section has a spring-loaded lock sleeve, which has to be rotated clockwise to unlock the connector and disconnect the upper section. Both sections are locked together when the sleeve is rotated back and held in the lock position by the torque spring. Both sections have a sealed ballistic transfer: Donor transfer on the top (trigger charge), and the receiver on the bottom (receptor booster). All explosives used for the ballistic transfer are secondary explosives. A slick joint at the bottom of the connector has a landing shoulder for precise positioning in the deployment stack[5].

CIRP Deployment Stack

The CIRP deployment stack, Fig. 4, is installed at the bottom of the lubricator, below the gate valves. It can be operated hydraulically or manually. It includes two sets of special CIRP ram actuators mounted on a CT combo BOP body that activate the lower No-Go rams with lock inserts, and the upper guide rams with rack inserts[4, 5].

1. The lower set of actuators closes the No-Go ram around the slick joint to provide a shoulder to hang the string on. The connector is then landed in the ram and the lock inserts are activated to grip the connector. This precisely locates the lock sleeve actuator (rack) and locks the connector against rotation.

2. The second set of actuators closes the guide ram around a "pinion" profile on the lock sleeve. Then the rack's inserts engage the lock sleeve and rotates it against the torque spring. The spring can then be pulled up to disengage the upper section of the CIRP connector.

Gate Valves

After actuating the CIRP stack to disconnect the CIRP connector, the upper gun section is pulled up in the lubricator above the gate valves. The gate valves are then closed and the lubricator bled off for retrieving the guns in the lubricator. The gate valves are effectively sealing the well while the gun is hanging in the CIRP stack below the valves and still under pressure while the gun section is retrieved. Note that the pressure barrier is the gate valves, and not a pipe ram type seal on the connector. The CIRP deployment system specifications are shown in Table 1.

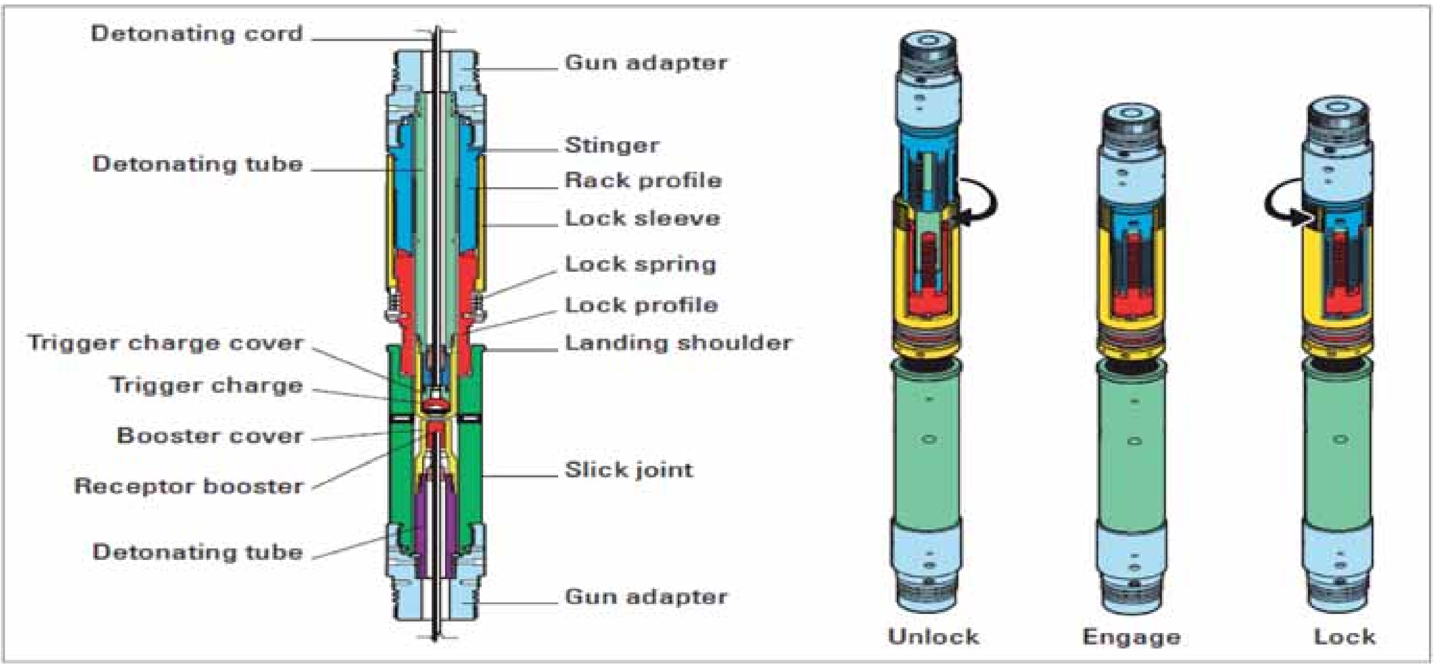


Fig. 3. Standard CIRP connector.

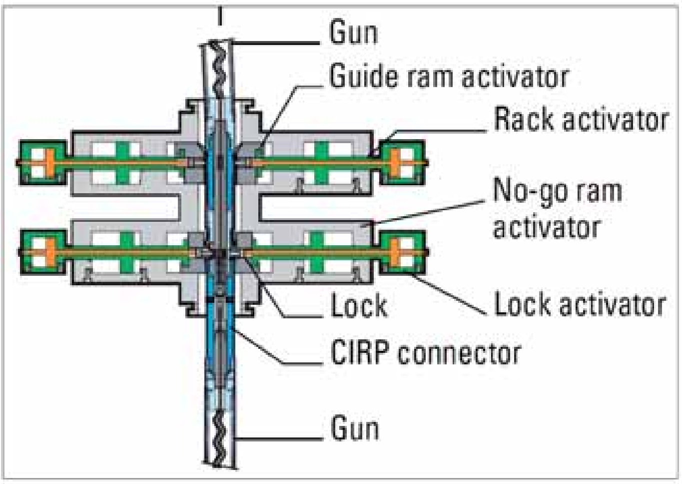


Fig. 4. Standard CIRP deployment stack

Details of run in hole (RIH) and pull out of hole (POOH) rig up and deployment/reverse deployment rig up are shown in Fig. 5 and Fig. 6, respectively.

CT Tower

A 50 ft CT tower, with flexible height, was available for the CT perforating jobs as shown in Figs. 7 and 8. The crane will still be needed to deploy and reverse deploy the guns, but during RIH/POOH the injector head is supported by the fifth floor with additional legs.

The advantages of the CT tower are:

- The entire pressure control equipment stack is chained to the tower, which eliminates any stress on the connections.
- Minimize nonproductive time caused by crane and weather during RIH/POOH.
- Easy access to injector head and all pressure control equipment at any time without the use of additional crane and man basket, which facilitates the operation of the Hydra-Conn.
- Guns stack system to increase efficiency of gun makeup and lay down.

Case Study

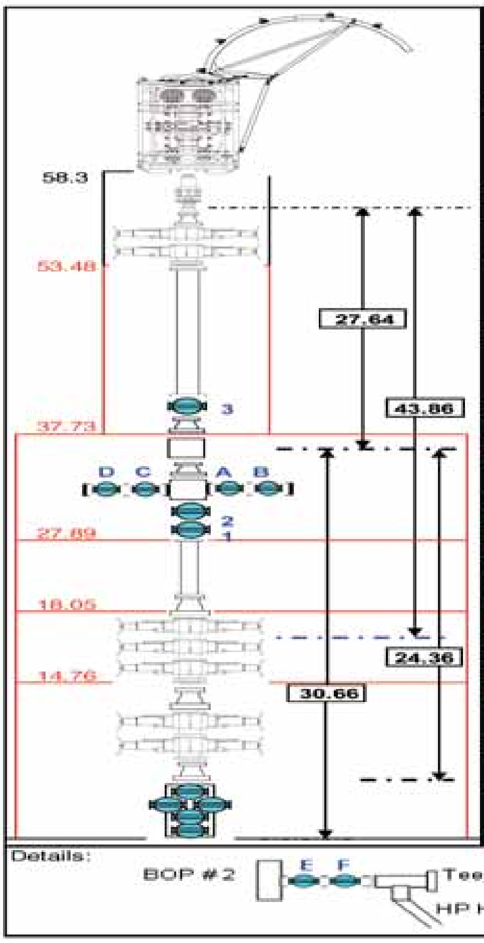
Well-A

Well-A is a 6⅛" open hole oil producer with horizontal section ~1,600 ft long from 9,397 ft to a total depth of 10,788 ft. The water cut increased more than 8 years

Gun Size, in	2	2½	2⅞	3⅜	3½	4½
Connectors						
Outside diameter, mm [in]	57.2 [2.25]	57.2 [2.25]	71.1 [2.80]	71.1 [2.80]	71.1 [2.80]	114.3 [4.50]
Temperature rating,† degC [degF]	204 [400]	204 [400]	204 [400]	204 [400]	204 [400]	204 [400]
Collapse pressure,‡ MPa [psi]	138 [20,000]	138 [20,000]	138 [20,000]	138 [20,000]	138 [20,000]	138 [20,000]
Shot-to-shot distance,§ cm [in]	117 [46]	117 [46]	117 [46]	117 [46]	117 [46]	119 [47]
Make-up length, cm [in]	86.2 [33.94]	86.2 [33.94]	85.6 [33.70]	85.6 [33.70]	85.6 [33.70]	89.7 [35.33]
Slick joint length, cm [in]	30.5 [12.00]	30.5 [12.00]	30.1 [11.84]	30.1 [11.84]	30.1 [11.84]	30.5 [12.00]
Tensile strength,‡ kN [lbf]	267 [60,000]	267 [60,000]	645 [145,000]	645 [145,000]	645 [145,000]	1,668 [375,000]
Compressive strength,‡ kN [lbf]	85 [19,000]	85 [19,000]	227 [51,000]	227 [51,000]	227 [51,000]	1,312 [295,000]
Nominal rotation of lock sleeve, °	15	15	15	15	15	15
Rack and Lock						
CIRP combi-BOP stack ID, mm [in]	103 [4.06]	103 [4.06]	103 [4.06]	103 [4.06]	103 [4.06]	130 [5.125]
Working pressure, MPa [psi]	69 [10,000]	69 [10,000]	69 [10,000]	69 [10,000]	69 [10,000]	69 [10,000]
Ram space out, center to center, cm [in]	29.2 [11.50]	29.2 [11.50]	29.2 [11.50]	29.2 [11.50]	29.2 [11.50]	36.8 [14.50]
Max. downward load on no-go rams, kN [lbf]	89 [20,000]	89 [20,000]	178 [40,000]	178 [40,000]	178 [40,000]	378 [85,000]
Max. upward pull on no-go rams, kN [lbf]	89 [20,000]	89 [20,000]	178 [40,000]	178 [40,000]	178 [40,000]	378 [85,000]

Note: For additional sizes and special applications, such as high-pressure, high-temperature, contact a Schlumberger representative.
† For 100 h, temperature rating can be increased with special seals.
‡ Collapse pressure rating is at 67% of yield strength; tensile and compressive strengths are at yield strength.
§ Nominal shot-to-shot distance; exact distance depends on shot density and phasing option of gun.

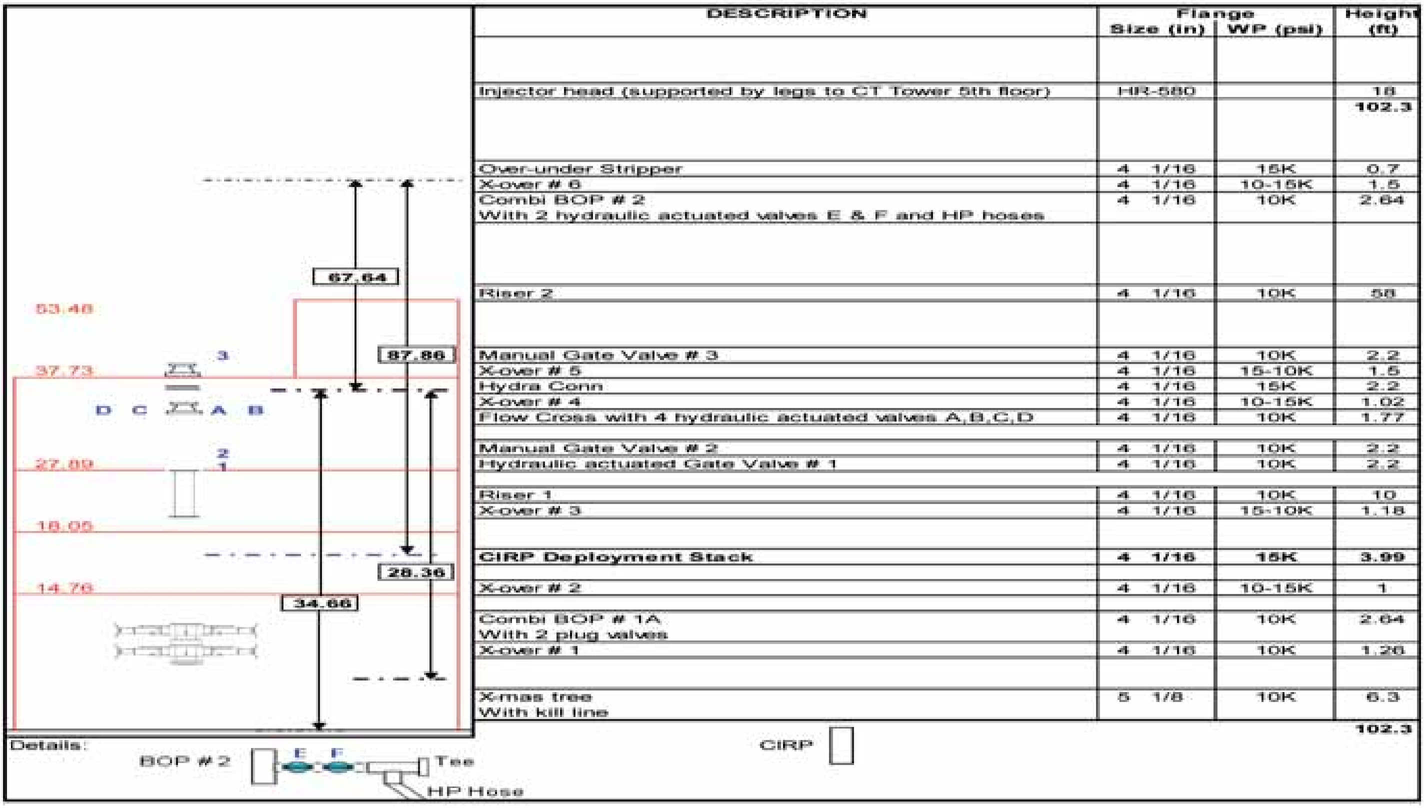
Table 1. CIRP deployment system specifications



DESCRIPTION	Flange Size (in)	Flange WP (psi)	Height (ft)
Injector head (supported by legs to CT Tower 5th floor)	HR-580		18
			58.3
Over-under Stripper	4 1/16	15K	0.7
X-over # 6	4 1/16	10-15K	1.5
Combi BOP # 2 With 2 hydraulic actuated valves E & F and HP hoses	4 1/16	10K	2.64
Riser 2	4 1/16	10K	18
Manual Gate Valve # 3	4 1/16	10K	2.2
X-over # 5	4 1/16	15-10K	1.5
Hydra Conn	4 1/16	15K	2.2
X-over # 4	4 1/16	10-15K	1.02
Flow Cross with 4 hydraulic actuated valves A,B,C,D	4 1/16	10K	1.77
Manual Gate Valve # 2	4 1/16	10K	2.2
Hydraulic actuated Gate Valve # 1	4 1/16	10K	2.2
Riser 1 (1x6ft)	4 1/16	10K	6
X-over # 3	4 1/16	15-10K	1.18
CIRP	1 1/16	15K	3.99
X-over # 2	4 1/16	10-15K	1
Combi BOP # 1A With 2 plug valves	4 1/16	10K	2.64
X-over # 1	4 1/16	10K	1.26
X-mas tree With kill line	5 1/8	10K	6.3
			58.3

CIRP

Fig. 5. RIH/POOH CT rigup.



DESCRIPTION	Flange Size (in)	Flange WP (psi)	Height (ft)
Injector head (supported by legs to CT Tower 5th floor)	HR-580		18
			102.3
Over-under Stripper	4 1/16	15K	0.7
X-over # 6	4 1/16	10-15K	1.5
Combi BOP # 2 With 2 hydraulic actuated valves E & F and HP hoses	4 1/16	10K	2.64
Riser 2	4 1/16	10K	58
Manual Gate Valve # 3	4 1/16	10K	2.2
X-over # 5	4 1/16	15-10K	1.5
Hydra Conn	4 1/16	15K	2.2
X-over # 4	4 1/16	10-15K	1.02
Flow Cross with 4 hydraulic actuated valves A,B,C,D	4 1/16	10K	1.77
Manual Gate Valve # 2	4 1/16	10K	2.2
Hydraulic actuated Gate Valve # 1	4 1/16	10K	2.2
Riser 1	4 1/16	10K	10
X-over # 3	4 1/16	15-10K	1.18
CIRP Deployment Stack	**4 1/16**	**15K**	**3.99**
X-over # 2	4 1/16	10-15K	1
Combi BOP # 1A With 2 plug valves	4 1/16	10K	2.64
X-over # 1	4 1/16	10K	1.26
X-mas tree With kill line	5 1/8	10K	6.3
			102.3

Fig. 6. Deployment/Reverse deployment CT rigup.

Fig. 7. CT tower.

Fig. 8. CT tower rigup during deployment/reverse deployment.

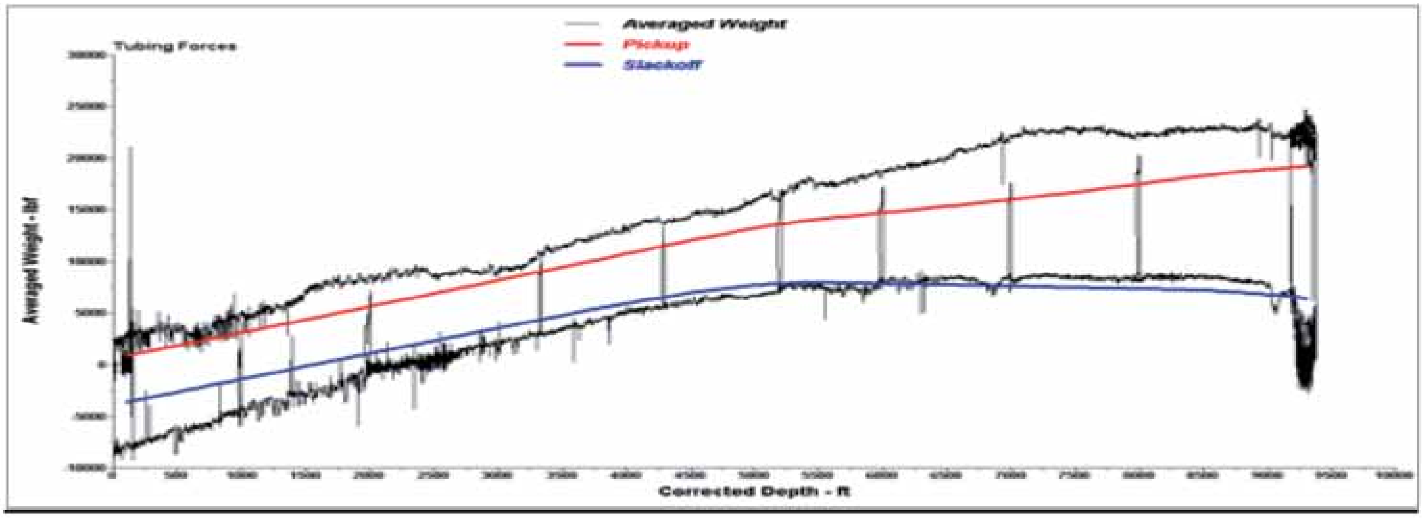


Fig. 9. Measured weights vs. simulated weight from TFM.

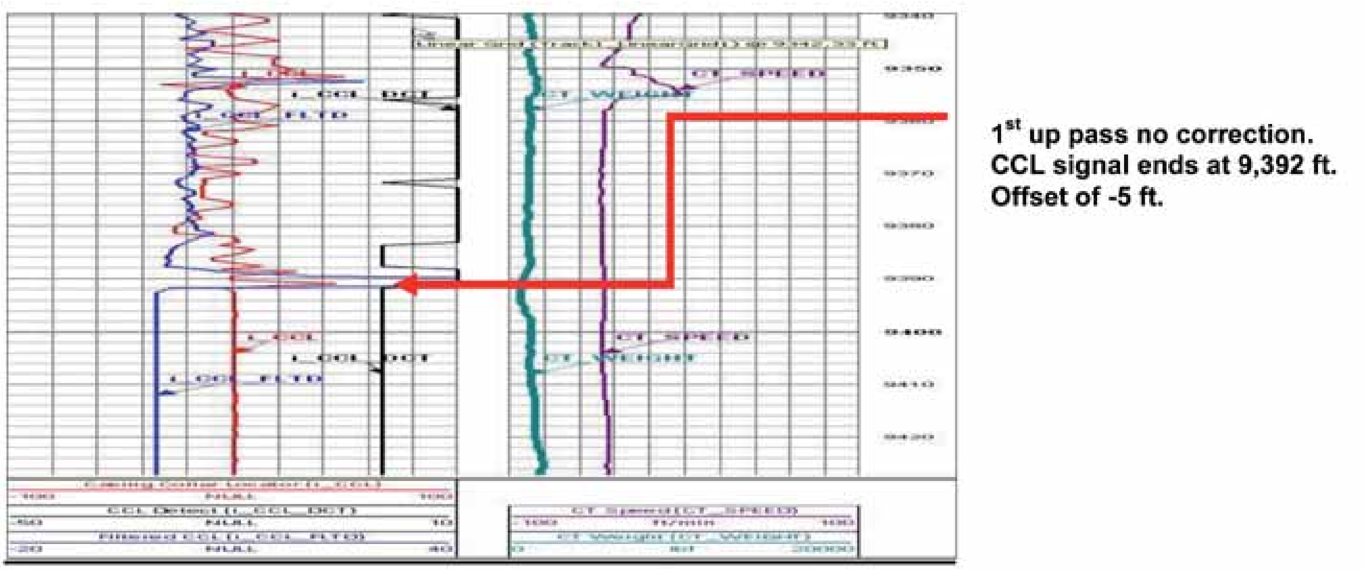


Fig. 10. First "up CT pass" no depth correction.

ago with a simultaneous decrease in oil production. A production log was obtained prior to WSO indicated a 96% water cut and most of the oil production coming from clusters of conductive carbonate fractures.

Based on the production log's analysis, the remedial action for this well was to isolate the open hole and following by underbalance perforation of the upper production formation to minimize perforation damage and to enhance productivity in a rigless environment.

Job Execution

The WSO and perforating treatments were planned and performed as follows:

1. CT RUN 1: Wellbore drift and cleanout with FOECT pressure-temperature casing collar locator (FOECT-PTC) sensors and with a high-pressure rotating jetting tool:

• Check wellbore accessibility and cleanup casing ID across inflatable packer setting depth.
• Correlate depth with CCL for precise packer setting depth and perforation run.
• Verify actual BHT for cement recipe reconfirmation tests.

During CT RUN 1 no abnormalities were observed in both CT weights and pressure. The tubing forces

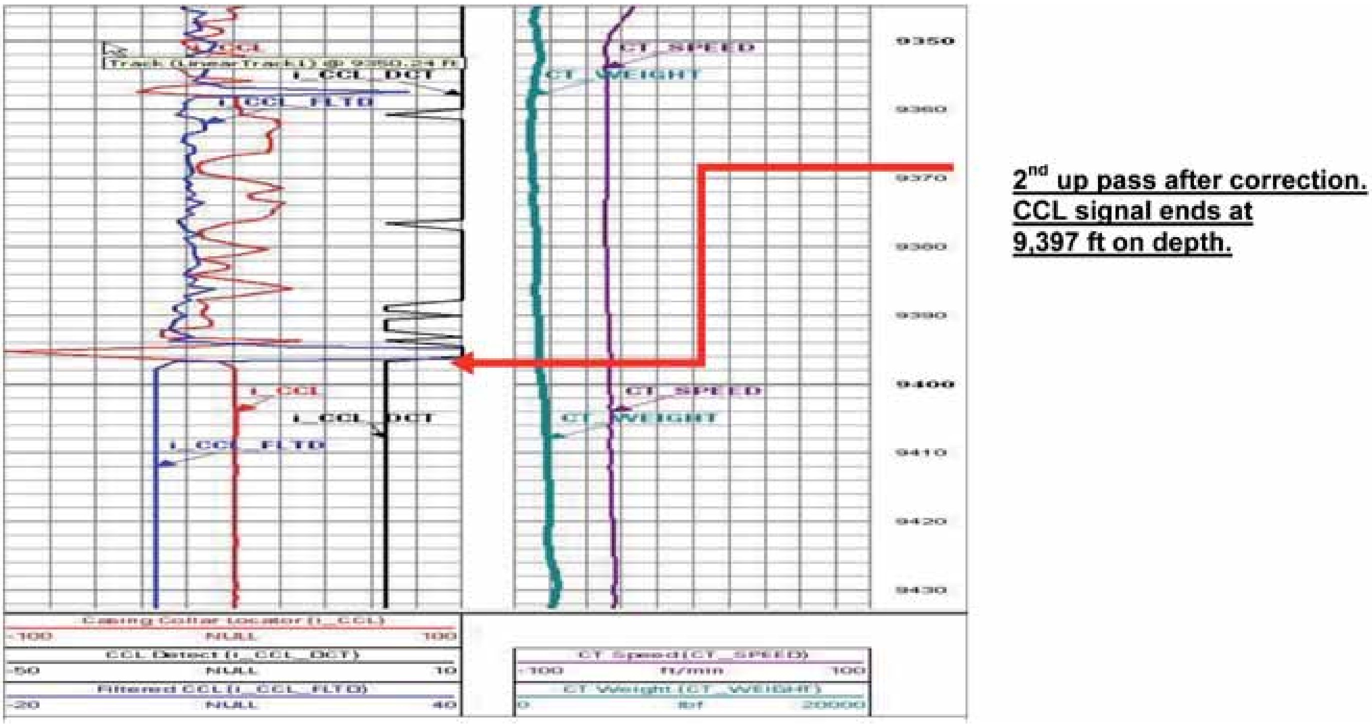


Fig. 11. Second 'up CT pass' after depth correction.

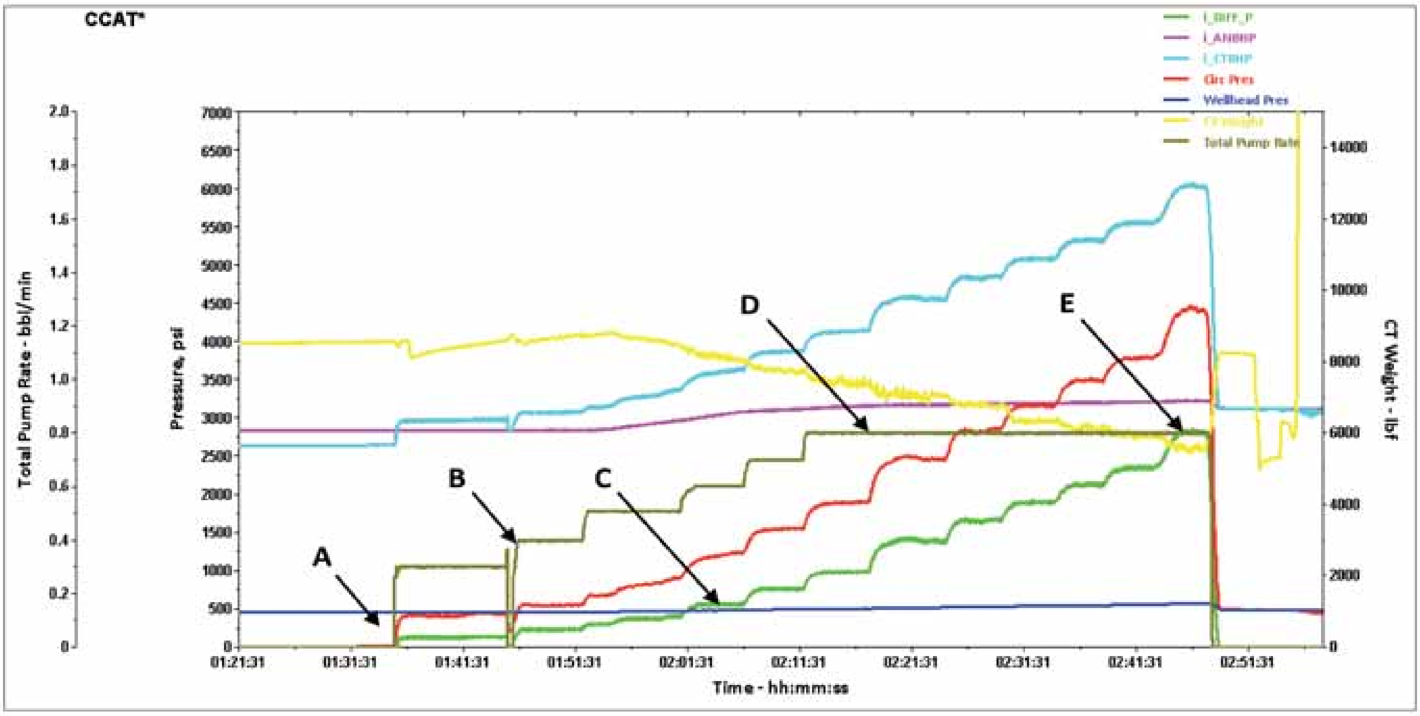


Fig. 12. Inflatable packer setting treatment plot.

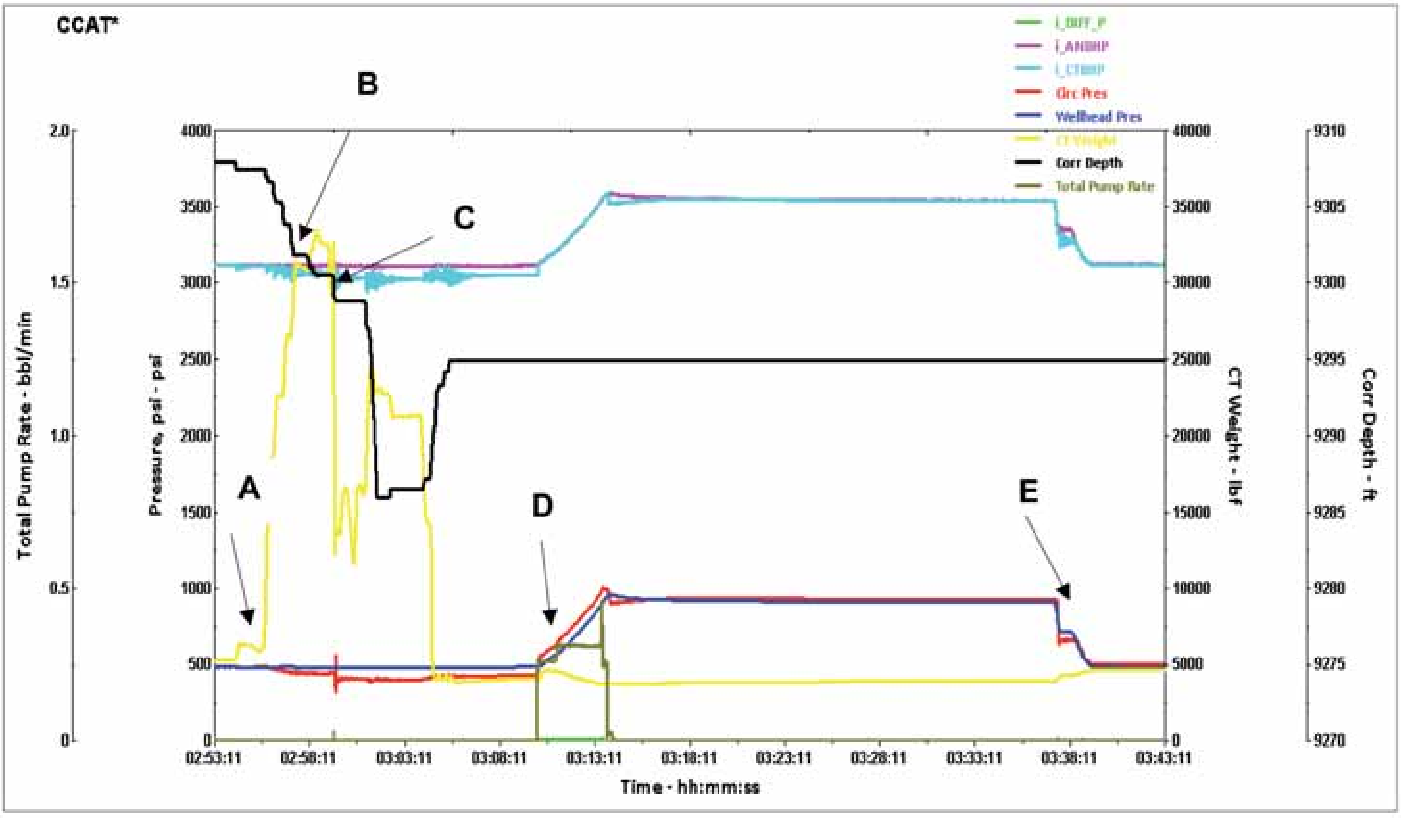


Fig. 13. Inflatable packer disconnect treatment plot.

model (TFM) showing matching weight trends between the simulated pickup and slackoff weight and the measured averaged CT weight, Fig. 9.

2. CT RUN 2: Inflatable packer run with FOECT-PTC sensors:

• Correlate depth before setting packer using CCL.
• Confirm packer setting, inflation and disconnect process is as per design.
• Control downhole differential pressure inside and outside the CT while placing the cement plug on top of the inflatable packer to eliminate the risks of cement swapping effect.

Depth correlation was a very critical point to ensure accuracy of packer setting depth at just above the liner shoe in the horizontal section. FOECT-PTC BHA was utilized for this run with depth correlation by using CCL. It is important to keep the depth correlation as close to the target packer setting depth as possible. During the design phase, the decision was taken to perform the depth correlation by locating the end of the 7" OD liner at 9,397 ft. Since beyond this depth is an open hole, CCL will show zero readings as soon as it enters the open hole section. With this, the end of the liner can be pinpointed and the depth can be corrected accordingly.

Figures 10 and 11 show the summary of the depth correlation done during CT RUN 2.

After performing the depth correlation across the end of the 7" liner, the center of the inflatable packer element (i_Depth_Tool_Reference) was placed in the slack off weight at 9,300 ft. A step by step of the inflation process is illustrated in Fig. 12.

A. Begin pumping to start the inflation process.
B. Build up pumping rate 0.1 bpm every +/- 10 minutes while continuously monitoring pressure stabilization.
C. Initial inflation starts at differential pressure – 400 psi.
D. Maintain stable pumping rate at 0.8 bpm. Wait for pressure to build up to maximum inflation pressure.
E. At maximum inflation pressure of 2,800 psi differential pressure. Pressure stable. Stop inflation process.

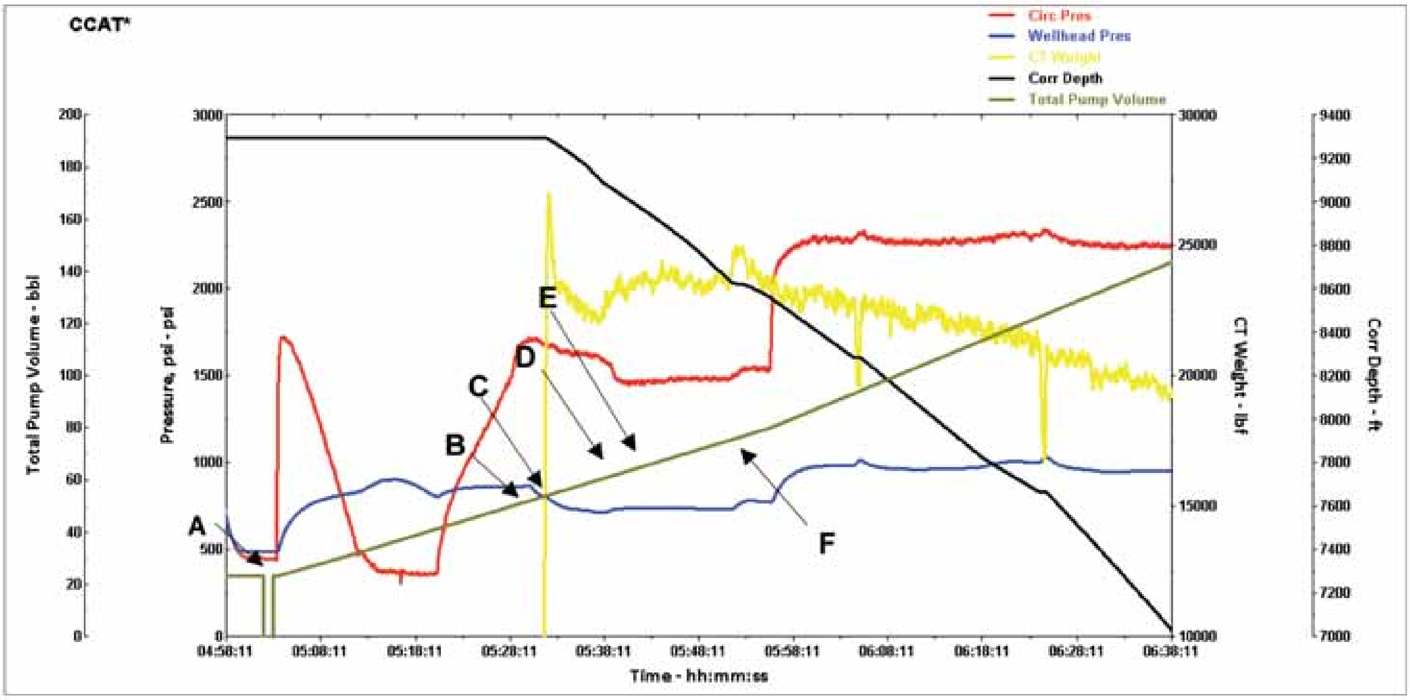


Fig. 14. Cement plug spotting treatment plot.

Spacer	5 bbl
Cement	8 bbl
Spacer	5 bbl
Contaminant	20 bbl

Table 2. Cement plug and spacer volumes

After successfully inflating, the packer was disconnected, by applying 7,000 lbf over pull downhole. Figure 13 shows the over pull to disconnect the packer and the pressure test of 1,000 psi to confirm packer sealing.

A. Begin POOH to create over pull. CT weight increasing to hanging weight of 23,000 lbf.
B. At the surface, the CT weight of 34,000 lbf (downhole over pull of +/- 7,000 lbf).
C. Sudden drop of weight, clear indication of over pull and packer disconnected.
D. Perform pressure test of 1,000 psi on packer, pressure stable and holding good.
E. Bleed off pressure.

After confirming the packer was sealing, all fluids required for the cement plug was prepared.

3. Cement plug placement on top of the inflatable packer

The volumes required for the cement plug and spacers were mixed on location after successful inflatable settings, Table 2.

Figure 14 shows the cement plug spotting sequence.

A. Total volume 23 bbl, zero volume was made when cement enters the CT (8 bbl cement + 5 bbl behind spacer + 20 bbl contaminant).
B. Total volume 52 bbl, cement at nozzle (CT volume 52 bbl).
C. Total volume 53.5 bbl, begin POOH (50 ft of cement out of nozzle).
D. Total volume 60 bbl, all cement out of nozzle, depth 9,085 ft.

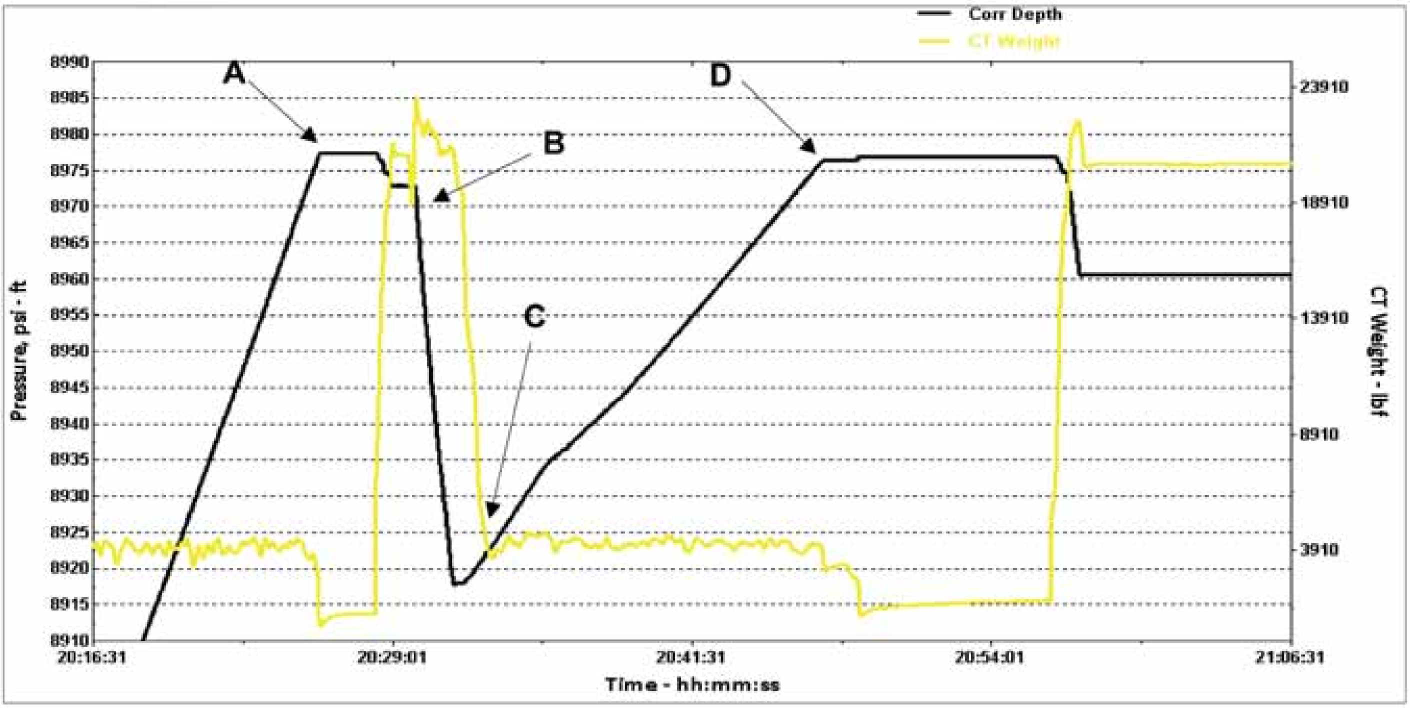


Fig. 15. Tag top of cement plug

E. Total volume 65 bbl, all spacer out of nozzle, depth 8,935 ft.
F. Total volume 75 bbl, all contaminant out of nozzle, depth 8,635 ft.

After successfully spotting the cement plug, CT was POOH while keeping the well shut-in with back pressure of 1,000 psi. As per the cement QA/QC lab tests, it was recommended to wait 36 hours for the cement to be fully set and gain sufficient compressive strength before RIH again to tag the top of the cement, Fig. 15.

4. CT RUN 3: Tag the top of the cement plug with FOECT-PTC sensors:

• To verify the top of the cement plug is at design depth.
• Pressure test the cement plug.
• Confirm the reach of the dummy BHA to the required depth and reconfirm depth correlation with the CCL GR.
• Displace wellbore to diesel for underbalance conditions and verify actual BHP.

A. First tag depth at 8,978 ft (expected TOC at 9,100 ft).
B. POOH to make a second tag.
C. RIH to make a second tag.
D. Second tag depth at 8,978 ft.

After TOC depth reconfirmation, the plug was pressure tested to 1,500 psi, Fig. 16. Right after that, the well was displaced with diesel in preparation for the following perforation run.

5. CT RUN 4: Dummy run with perforation guns run with FOECT-PTC GR sensors and tubing conveyed perforating (TCP) e-Fire system:

• Deployment.
• Real-time depth correlation with the CCL GR.
• Confirm the reach of the dummy BHA to the required depth and reconfirm depth correlation with the CCL GR.
• Reverse deployment.

The dummy run started with the deployment process with FOECT PTC (CCL GR) tool, TCP e-Fire with 40 ft of 2.875" spent guns. Two types of well control stack configuration were used during this job. One is for deployment/reverse deployment and the other one will be during RIH/POOH. The difference between the two is the length of the risers used. For the deployment/reverse deployment, 58 ft of risers were used where as

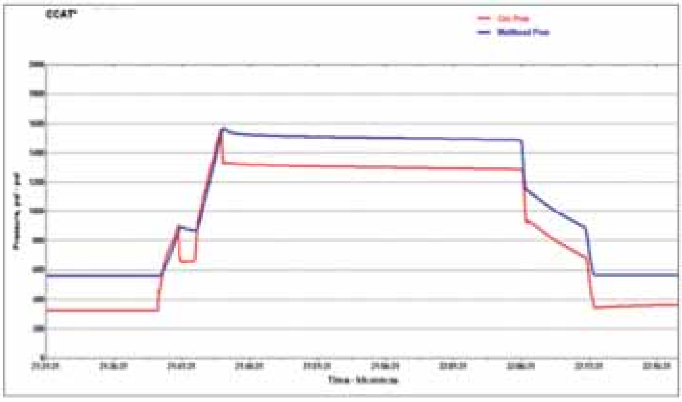


Fig. 16. Pressure test cement plug at 1,500 psi

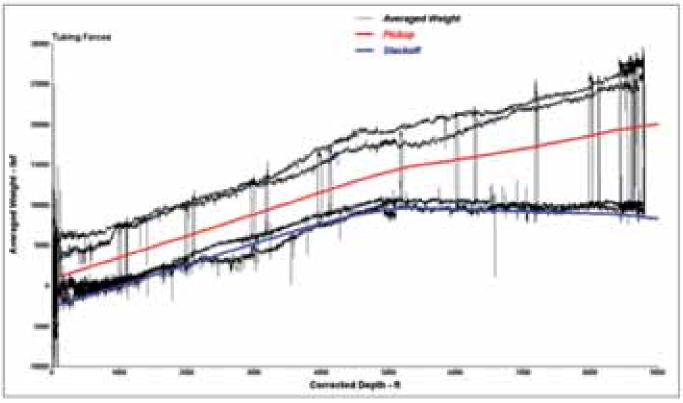


Fig. 17. Measured weights vs. simulated weight from TFM during perforation dummy run.

for RIH, 24 ft of risers were used, Figs. 5 and 6.

Figure 17 shows the measured weights vs. the simulated weight from the TFM during the perforation dummy run. No abnormalities were seen throughout the run. Weight trends during both runs were the same.

Once at depth during the dummy run, a flow rate test was done to simulate the actual firing sequence. CT was POOH to the surface and began the reverse deployment for the dummy guns. It was then followed by the deployment of the live guns.

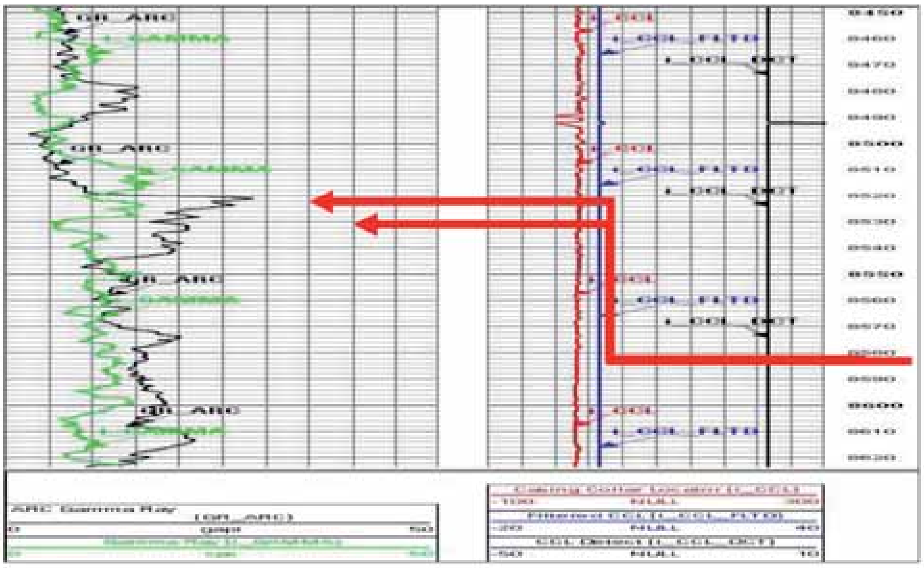
6. CT RUN 5: Perforation guns run with FOECT-PTC GR sensors and TCP e-Fire system:

•Deployment.
•Real-time depth correlation with CCL.
•Perforation.
• Reverse deployment.
• N_2 lifting.

After completing the deployment for the 120 ft of the live perforation gun, CT was ready to RIH. Depth correlation passes were done during this job using the GR and the CCL features from the ACTive PTC tool. Correlation was started from the surface. For the entire operation, CT aided design and evaluation system together with decipher software were used for the real-time FOECT PTC data acquisition.

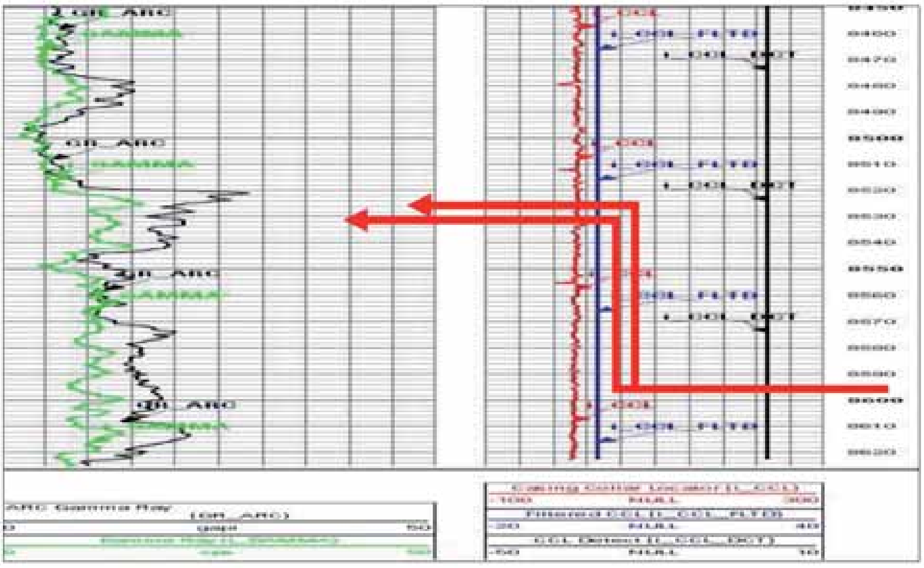
The reference log was verified to be the log used to select the perforation interval. It gives a GR log from a depth of 8,225 ft to 9,399 ft with very clear peaks and shapes that will be used to tie in with the GR log from the correlation passes. Correlation passes are done step by step:

• RIH down to TD, start correlation from the surface and write down a rough depth correction to tie in the GR log starting from a depth of 8,225 ft.
• Once at TD, POOH with speed 30 ft/min and write down the offset for depth correction.



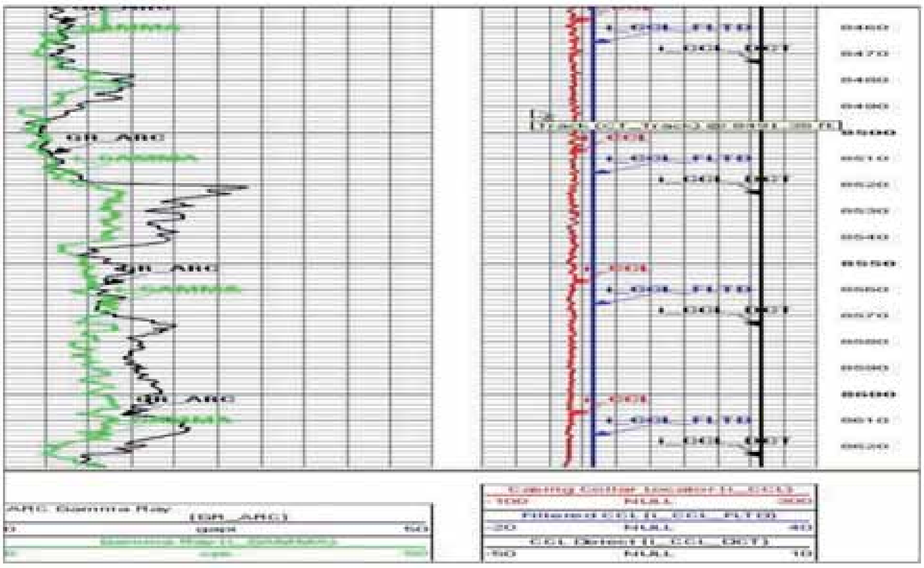
1st up pass no correction, offset of -14 ft.

Fig. 18. First 'up CT pass' no depth correction (live perforation run).



2nd up pass after correction. Offset of -14 ft.

Fig. 19. Second 'up CT pass' after depth correction (live perforation run).



3rd up pass after correction. On depth.

Fig. 20. Third 'up CT pass' on depth after depth correction (live perforation run).

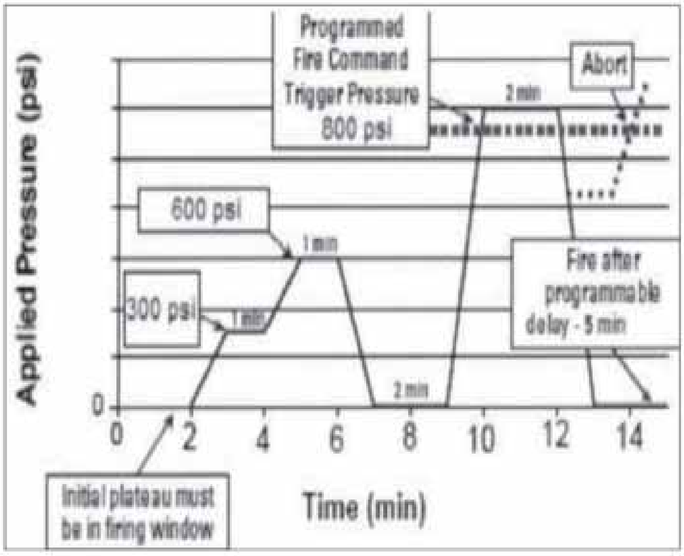


Fig. 21. Designed pressure signals during firing sequence.

• Correct the depth and RIH again. This time the GR log should be roughly tied in with the GR from the reference log.
• Another POOH is required to give a confirmation that the corrected depth was correct. All significant shapes and peaks should match. With this, the CCL can now be tied in with the GR from the correlation log.
• RIH again below the shooting depth and POOH to keep the CT in tension for the perforation. POOH from 100 ft to 200 ft below shooting depth to catch the shapes/peaks and the correct CCL signal that was already tied in with GR from corrected correlation log for final confirmation.

Figures 18, 19 and 20 represent the depth correlation done during the live perforation run.

The firing sequence for the first loaded guns using the TCP e-Fire firing head started after CT stops at the shooting depth. The firing head was activated using pressure signals by applying pressure down the CT tubing annulus. Figure 21 shows the expected pressure signals during the firing sequence.

A clear weight and pressure provides an indication that signals that the guns were fired as planned. Wellhead pressure showed a good response right after firing. CT was POOH right after the guns fired, to avoid any debris from the perforation entering the CIRP swivel connector, which could later make reverse deployment difficult.

Table 3 compares the operational time efficiency of the conventional perforation treatment on CT vs. CT CIRP perforation for Well-A.

Results

The job was executed as designed, and the procedures were followed to ensure that the different stages involved in the operation served their purpose. The FOECT technology was used to ensure service quality by correlating proper depth and ensuring correct downhole pressures and temperatures for setting the packer, and for both confirming the cement design and conditions during the cement job. The CCL and GR were utilized to ensure the CT depth was accurate, by correlation with initial CCL and reference log for GR.

The CIRP perforating technique in an oil field in Saudi Arabia was safely and successfully implemented. CIRP technology paired with the FOECT CT has proven to be a highly advantageous method for perforating. Some worthwhile aspects of this job are value saved for the operator as compared to other alternatives, reduced risk by reverse deploying only once, operation efficiency and simplicity, less time consumption and not to mention the excellent production results achieved as a result of the underbalanced perforation.

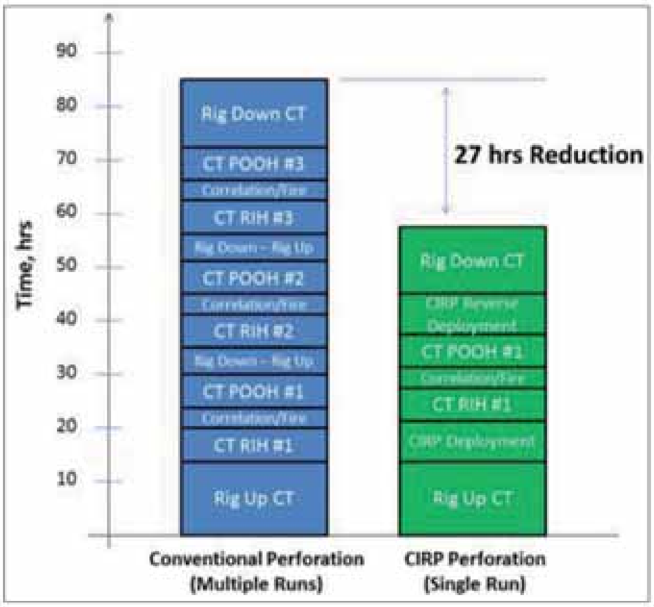


Table 3. Operational time comparison. Conventional CT perforation vs. CT CIRP perforation 200 ft gun length.

Well-A post remedial production showed that a previously dead well flowed at 10,000 BOPD with 12% water cut.

Conclusions and Recommendations

The results of these WSO treatments proved the viability of an innovative technique using FOECT and CIRP, controlled depth and monitored bottom-hole parameters to isolate water producing intervals in the cased hole section, allowing proper placement of cement into the horizontal section. The CIRP perforating technique has been proven to deliver results and can be deployed in Saudi Arabia's oil fields when required now and in the future. In summary:

1. The FOECT BHP reading also prevented packer damage during inflation of the packer. The pressure measurements prevented the BHP from exceeding the packer differential limits and reservoir frac pressure during cement squeeze.

2. This technology is a viable method to communicate directly and continuously downhole with the well-bore, reservoir or tools conveyed via CT. A direct communication with downhole conditions avoids relying on calculating parameters from surface readings, which are often far from real downhole conditions. This direct link helps operators to come up with the right decisions on site.

3. Use of FOECT technology allowed having good correlation while job perforating.

4. CT perforating proved beneficial for deploying live guns under a high-pressure scenario as well as proven access.

5. The system proved 100% reliable while having no missed runs.

6. There was no operational incident and the CIRP modular perforating system proved a great value while not leaving any guns unfired.

7. The objectives were met and this new technology has been recommended for extended application.

8. This new technology proved valuable, not only because of saving time while comparing with regular rig perforating, but also because of increased well potential and stimulation avoidance.

9. CT perforating competes with other perforating techniques (like CT hydrajetting) since perspective of

single run/underbalance and cost avoidance.

10. As a recommendation, future jobs will utilize the real-time downhole TC tool to help confirm that the packer was set and anchored and to ensure that the packer stayed connected during cement injection below the upper packer. Additionally, the TC sub can be used to confirm that the packer will release as designed.

Acknowledgements

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Nomenclature

i_CTBHP Inner Coiled Tubing Bottom-hole Pressure

PTC-G-TC Pressure-Temperature Casing Collar Locator - Gamma Ray - Tension Compression

Biographies

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Anton joined Schlumberger in 2001 and has held a variety of operational management, technical and marketing positions in Europe, Asia and the Middle East. His expertise covers coiled tubing, and stimulation and fracturing.

In 2000, Anton received his M.S. degree in Mechanical Engineering from the Russian State Technical University of Volgograd, Volgograd, Russia. He is a member of the Society of Petroleum Engineers (SPE).

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He received B.S. degree in Civil Engineering from the Malaysia Technology University, Johor Bahru, Malaysia, in 2007. Azwan is a member of the Society of Petroleum Engineers (SPE).

Power Conditioning and Backup Protection of Pipeline SCADA Systems in Harsh Environments

By Michael A. Stout, Vice President of Engineering, Falcon Electric, Inc.

The management of complex gas and oil pipeline systems demands constant, reliable system-wide control. Typically this is accomplished with system-wide monitoring and control using sophisticated System Control and Data Acquisition (SCADA) equipment. The remote sensors, related Programmable Logic Controllers (PLCs) and client software are vital to the reliable supervision of product flow control, pipeline and manifold internal pressures, product measurement, etc. The location of remote SCADA PLCs and sensors are in some of the harshest environments on earth. Many are responsible for the monitoring and control of critical functions requiring absolute reliability. A reliable source of computer-grade primary and backup power is an essential element to assuring system reliability. Backup power is essential to maintain monitoring and control functions in addition to assuring the pipeline's infrastructure and safety. Without the SCADA system's continuous measurement and control, pumps and valves that control pressures within the pipeline and its manifolds could result in increased pressures potentially bursting the pipe causing costly hazmat spills and cleanups. Moreover, on steep slopes, check valves could remain open during a loss of power to pumps causing damage to pipes and valves on the downhill side. To further compound the problems, SCADA system PLCs are often sensitive to power pollution such as voltage spikes, sags, surges and common mode noise. These problems can result in unreliable PLC operation or failures. The solution to these problems is the addition of an on-line double- conversion uninterruptible power supply (UPS).

Power Protection for Harsh Power Environments

The double-conversion on-line UPS technology, through its continuous regeneration of new AC power, provides the highest level of power conditioning and protection (figure 1). On-line UPS technology is ideal for use as a combination high performance power conditioner and battery backup system. When used in a controlled temperature environment ranging from 0ºC to 40ºC (32ºF to 104ºF), most domestically available on-line UPSs can meet pipeline usage requirements as most have been tested and approved for operation over this temperature range by a safety agency such as Underwriters Laboratories (UL). However, in remote locations where SCADA monitoring equipment is located, the use of on-line UPS technology is required. Many remote outdoor installations are situated in harsh power environments where power sensitive PLCs and on-line UPSs may be installed inside buildings without any climate control systems, or in protective NEMA-rated enclosures. For example, the outdoor temperature in Phoenix, Arizona in the summer can be over 48°C (120ºF), while the low temperature in Prudhoe Bay, Alaska, can be below 30ºC (-22ºF). Even though the on-line UPS is protected from the remaining elements, attempting to use an off-the-shelf UPS in these extreme temperature environments is a poor decision and often results in a UPS failure.

A standard off-the-shelf on-line UPS having a UL or ETL Listing for operation over a 0ºC to 40ºC temperature range typically has been submitted by the manufacturer to a safety agency for an engineering evaluation. As

Falcon UPSs in NEMA-rated enclosure are listed to operate across wide temperatures.

part of the evaluation, a temperature profile is taken of the highest heat generating components and heatsinks to assure they do not exceed their maximum temperature ratings, while the UPS is operated at the maximum temperature specified by the manufacturer. A UPS incorporates many high power components that can over-heat and not only cause the UPS to fail, but present a risk of an internal UPS fire.

The safety agency also reviews the types of circuit board and plastic materials used in construction of the UPS with regards to their temperature ratings and limits. Due to the largest part of the UPS market demand being for products rated for use in temperature controlled environments, most on-line UPS manufacturers design their products for operation in the standard 0⁰C to 40⁰C operating environment and submit them to the safety agency for evaluation over the same operational

> "To meet the demand for wide temperature range UPS and power conversion products, a few manufacturers are designing products specifically to not only survive in these difficult environments, but to provide superior performance, while greatly reducing the servicing requirements."

temperature range. Installing this UPS in a building or NEMA enclosure without proper temperature control in the summer in Arizona would be using the UPS outside safety agency's product listing status. In many cases, since the UPS was designed for use in a limited temperature environment, internal components that were near their temperature limits when tested could exceed their maximum temperature ratings. This will result in the UPS having a greatly reduced reliability and service life, or an outright failure. At the higher temperatures of Arizona, plastics used in the UPS construction and battery can become deformed or cracked. The standard UPS battery used is typically not rated for temperatures above 40°C to 50°C. Further, per the battery manufacturer's rated 50°C temperatures, the battery service life can be severely reduced from five years to a few months.

Battery Weakness

Temperatures below 0°C present their own set of unique problems. Due to the electro/chemical design of most Valve Regulated Lead-Acid (VRLA) batteries in temperatures below -20°C, depending on the battery design, can impair the batteries ability to deliver sufficient current to power the UPS properly. The amount of battery runtime can be reduced to less than 50 percent of its normal time when operated at 25°C. Below -40°C the electrolyte inside electrolytic capacitors used in the circuitry of the UPS can greatly lower the capacitor's capacitance or even freeze causing capacitors to rupture. This can cause the internal electrolytic capacitors to slowly dry out, resulting in eventual UPS failure. Below -40°C, if not rated for this low temperature, some integrated circuits and optical isolator devices can function improperly causing the UPS to go to an alarm condition until warmed up. Again, a full UPS failure can result. At this low temperature, batteries can also freeze along with the plastics used in their case material becoming brittle and subject to cracking. As the battery electrolyte freezes it expands the plastic case and can cause the batteries to leak acidic electrolyte inside the UPS when the ambient temperature raises enough to allow the batteries to thaw out. This often renders the UPS unusable, requiring it to be replaced. A standard on-line UPS having an operational temperature rating of 0°C to 40°C should not be installed in protected outdoor locations having temperature extremes outside its rated limits, yet it is often attempted.

To meet the demand for wide temperature range UPS and power conversion products, a few manufacturers are designing products specifically to not only survive in these difficult environments, but to provide superior performance, while greatly reducing the servicing requirements. The wider-temperature range products may be found in standalone UPS units or prepackaged turnkey systems from the manufacturer that are packaged into NEMA rated enclosures and cabinets. These systems are ready for immediate installation and operation and reduce the associated project engineering costs.

Typical Application

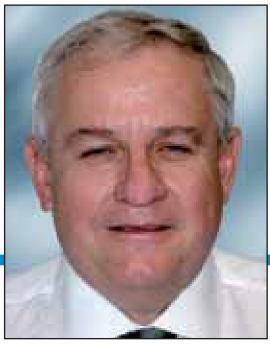
The pipeline starts at the well head and is an ideal example of how rugged, wide-temperature power protection equipment is installed and used. New drilling and well completion techniques such as Fracking have the potential to revitalize many of the played out oil and gas wells in the USA. Fluid is pumped down in to the well at very high pressures, about one thousand pounds per square inch. Since the fluid in the well is under such high pressure, should the utility power be lost to the pump it is imperative that the a valve be closed at the wellhead to prevent the fluid from coming back out of the well and causing a very expensive hazardous materials clean up. To eliminate this problem, a wide-temperature Uninterruptable Power Supply (UPS) is installed into a NEMA 3R rated enclosure on site. As the enclosure is located outside, the UPS is subjected to the wide range of temperatures experienced at the specific location. The UPS is used to provide backup power to both the onsite SCADA client system in addition to providing the power to close the wellhead valve.

SCADA Security

Due to the critical nature of gas and oil pipelines there is a great concern that the SCADA network may become the target of a terrorist or foreign government attacks. UPS systems pose the threat of providing a potential backdoor into the network, or at a minimum, the remote control of a UPS powering a critical element in the pipeline system. For instance, a UPS powering a PLC responsible for controlling a key pipeline valve or pump control may be subject to outside sabotage through its unsecured SNMP/HTTP, Telnet, SMTP and other ports on the network Ethernet interface. When connected to the SCADA network using unsecure SNMP/HTTP agents it could compromise a portion or the entire pipeline system. The need for password hashing, data encryption and the ability to turn off or secure unused communications ports is essential to assuring an adequate level of security. Ethernet based MODBUS interface is also supported by several manufacturers as most PLCs support direct MODBUS connectivity.

In conclusion, the double conversion on-line UPS, rated for proper operational temperature ranges provides the ideal solution to utility power related problems. It can be used as an active surge protector, battery backup, precision voltage and frequency regulator and if programmable, much more.

About the Author:



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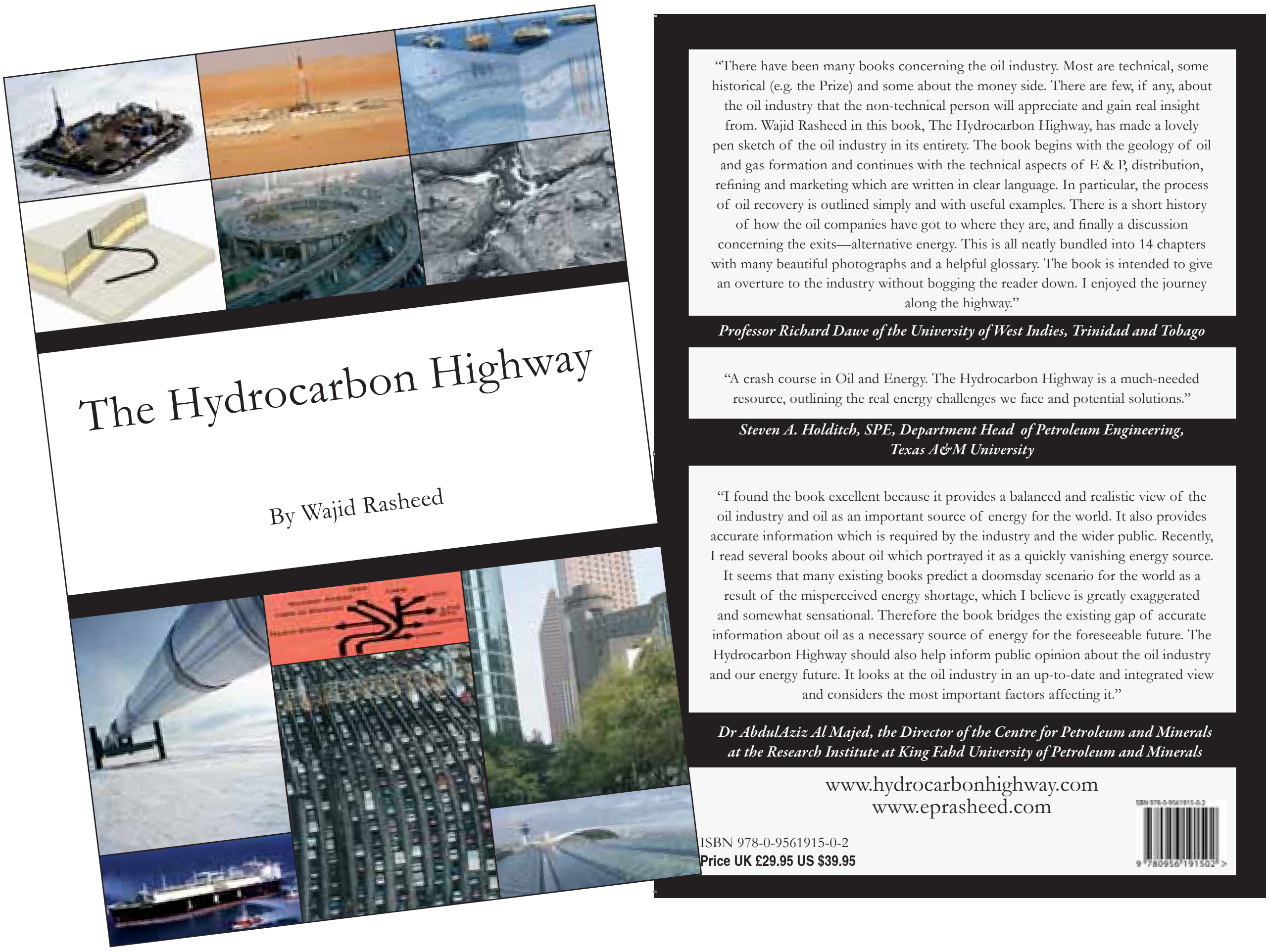
Refining



The downstream process of refining is an essential step in adding value to crude oil and creating different products made from oil and gas. An understanding of how such products are used in hydrocarbon applications is the basis of the supply and demand equation which ultimately defines exits from the Hydrocarbon Highway.

Picky Refineries

Refineries are designed and configured to handle a specific basket of crude, with a distinct preference for sweet and light. Over time, meeting this specific demand becomes difficult as production from original fields serving the refinery declines and new sources and new types of crude must be found to keep the refinery going. Oil companies have several options to keep production steady. They can find crude through the drill-bit, by acquiring competitors or by buying barrels. Only the last two allow some degree of control, but no guarantee of crude blends. Heavy oil from areas such as Canada and Venezuela, for example, cannot be refined at most refineries.

Homologous Series	General Formula	Example	Functional Group
Alkanes	C_nH_{2n+2} ($n \geq 1$)	CH_4, $n = 1$	
Alkyl	C_nH_{2n+1} ($n \geq 1$)	CH_3, $n = 1$	
Alkenes and Cyclic Alkanes	C_nH_{2n} ($n \geq 2$)	C_2H_4, $n = 2$	$C = C$
Alkynes	C_nH_{2n-2} ($n \geq 2$)	C_2H_2, $n = 2$	$C \equiv C$
Alcohols	$C_nH_{2n+1}OH$ ($n \geq 1$)	CH_4O, $n = 1$	- OH
Carboxylic acids	$C_nH_{2n}O_2$ ($n \geq 1$)	CH_2O_2, $n = 1$	- COOH
Carbohydrates	$C_n(H_2O)_n$ ($n \geq 1$)	$C_6H_{12}O_6$	

Where n represents the number of carbon atoms present.

Table 1 - Homologous Series

PdVSA (the Venezuelan National Oil Company [NOC]) was able to enter the US refining and distribution market as can be noted by the many 'CITGO – Cities Services' gas stations in the South. The spread of refining options enabled PdVSA to swap and trade crudes so that its own refineries could function more efficiently. This is because its heavy oil could only be refined at a single location. PdVSA's purchase of CITGO basically 'guaranteed' a market for Venezuelan crudes through its swaps and trades.

The bulk of global refineries are found mainly in consuming rather than producing countries which involves the costly transportation of crude or unrefined hydrocarbons[1]. This is a paradox because it would be far more efficient and far less costly to refine products near the source and transport the more valuable refined products to their various markets. It would also provide valuable jobs for producing countries. In addition, positioning refineries in densely populated consumer nations is problematic because of environmental concerns and the 'nimby' ('not in my back yard') factor.

Hydrocarbons*, as we have seen in *Chapter 3: What's in a Wet Barrel?*, are made up of different arrangements of volatile hydrogen and carbon compounds held together by weak Van der Waals forces. Variations in the strength and number of inter-molecular bonds, along with impurities, determine the viscosity and the melting and boiling points of most hydrocarbon compounds[2]. The stronger these forces and bonds, the heavier or more viscous the oil will be. As viscosity increases, more kinetic energy is needed to overcome the intermolecular forces holding the hydrogen and carbon together. For this reason, heavy oil is also less flammable as its compounds are less volatile, again due to increased intermolecular forces. The reverse also applies with much weaker forces hold together gas. Illustrating this are the two extremes of the hydrocarbon scale: methane gas (CH_4) and asphaltene ($C_{80}H_{162+}$)[3].

Homologous Series

In Chapter 3, we also saw that certain hydrocarbon compounds share the same general molecular formula. They form part of the homologous series as seen in Table 1. Alkanes (or paraffins) are saturated hydrocarbons that form the basis of most crude oil and natural gas. They have single bonds and are described by the general formula (C_nH_{2n+2})[4].

Alkanes cover the spectrum of petroleum from methane, ethane, propane, butane (aerosol propellants) and pentane to octane (gasoline), nonane (diesel and aviation fuel), hexadecane (fuel oil) and tetracontane (lubricating oil). Hydrocarbons that contain 35 or more carbon atoms are generally classed as bitumen, asphalt and tar. By far the most important end use of alkanes is combustion as fuel to provide heat and electric or motive power. In most cases, complete oxidation is not achieved, and varying amounts of incompletely oxidised fragments, carbon monoxide, and elemental carbons are produced[5].

Alkenes

Alkenes are unsaturated hydrocarbons. They have a double carbon bond and are characterised by the formula C_nH_2. The simplest alkene is ethene (C_2H_4)

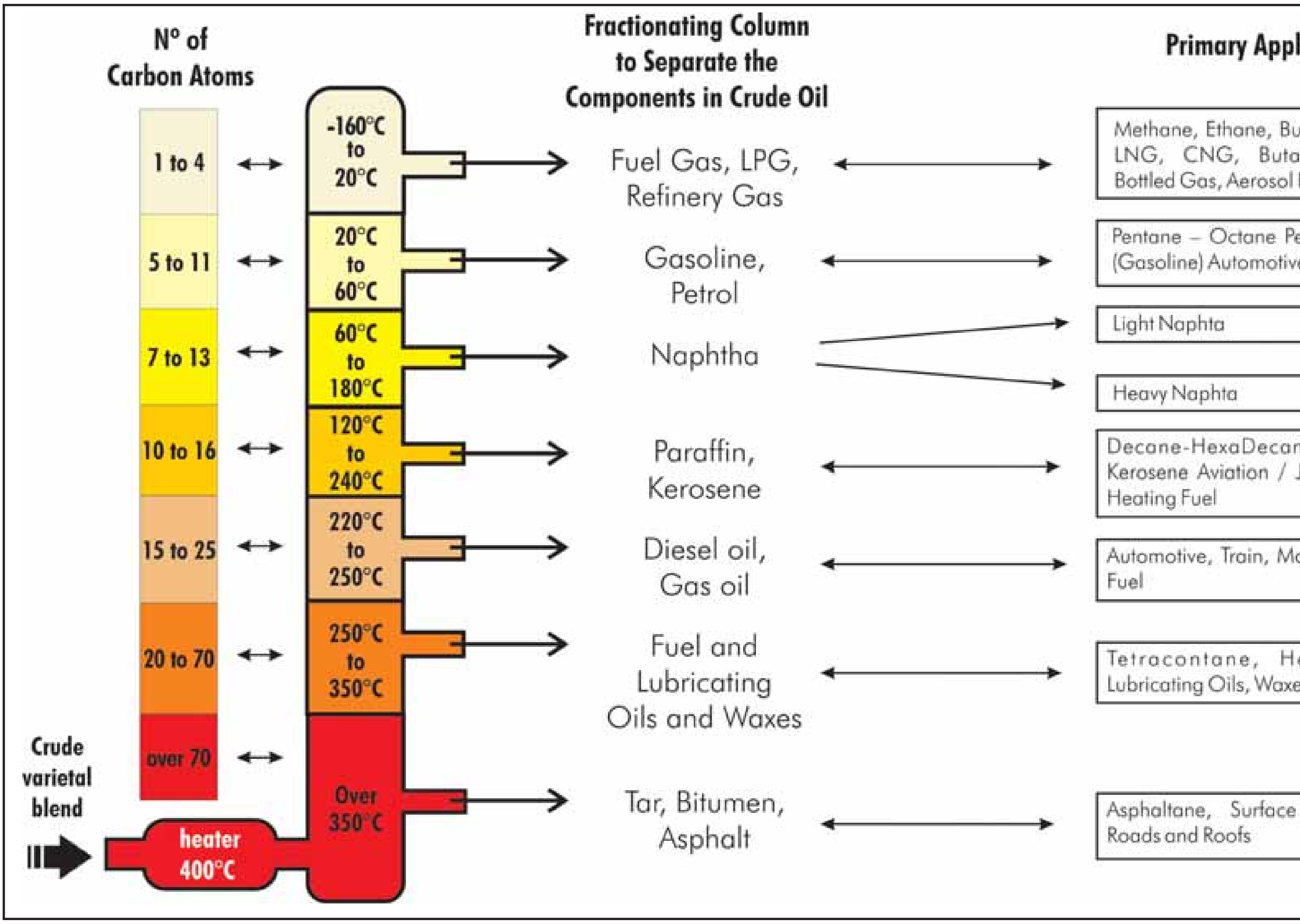


Figure 1 - The Fractional Distillation of Crude Oil and Gas (EPRasheed)

and it is often created by the steam cracking of Liquefied Petroleum Gas (LPG), ethane and light naphtha.

Ethylenes are used extensively as feedstock in many industrial products. They form the basis of plastics (polyethylene, polypropylene, polystyrene and polyvinylchloride or PVC) and industrial alcohol (ethanol). Alkenes themselves can also be produced by the dehydration of alcohol – see the production of ethanol in Chapter 13: Renewable Energy.

Alkenes are not found in crude oil and are one of the most valuable types of organic molecules in the chemical industry[6].

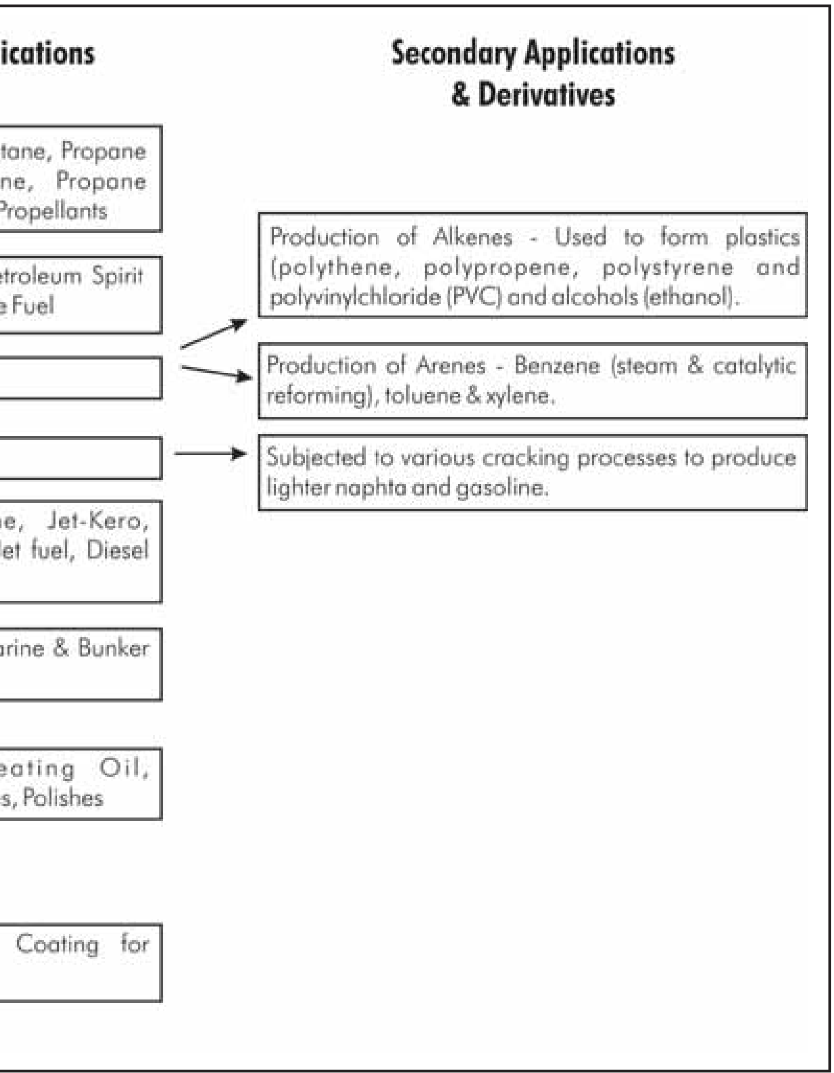
Cracking involves heating some of the less used fractions to a high temperature vapour and passing them over a suitable hot catalyst. The main products from cracking alkanes from oil are smaller alkanes (e.g. for petrol or diesel) and alkenes (e.g. for plastics).

Arenes

Arenes (or aromatics) are also unsaturated hydrocarbons, but they are characterised by a cyclic arrangement of six carbon atoms, the simplest of which is benzene (C_6H_6). Aromatics give rise to various pharmaceutical products, solvents and paints such as paracetamol (C_6H_4) and toluene (C_6H_5-CH_3)[7].

Fractional Distillation

Refineries will distill hydrocarbons into fractions according to their volatility; the most commonly known is petroleum spirit or gasoline. Fuels obtained during the refining process are LPG, naphtha, kerosene, gas-oil and fuel oil. Non-fuel products such as lubricants and asphalt (used in paving roads) can also be obtained during refining. After distillation, however, it is common for refined fractions not to match their commercial demands. Automotive fractions such as petrol and diesel are in great demand so heavier fractions such as heavy naphtha, gas-oil or



bitumen are subjected to secondary refining.

Cracking describes the process where heavier fractions are broken down to produce more of the lighter automotive fractions. Catalysts such as zeolite are commonly used to accelerate the cracking process and variations in cracking configurations exist according to the feedstock and final products required[8].

Derivatives such as perfumes and insecticides are also ultimately obtained from crude oil. Naphtha, gasoil, LPG and ethane are used as the raw material or feedstock in many petrochemical processes. There are more than 4,000 different petrochemical products, but those which are considered as basic products include ethylene, propylene, butadiene, benzene, ammonia and methanol. The main groups of petrochemical end-products include plastics, synthetic fibres, synthetic rubbers, detergents, chemical fertilisers, solvents, paints, protective coatings and pharmaceuticals.

Less Coke Please

Transportation and industry are the largest consumers of crude oil, specifically light distillates. Heavier fuel oils and 'solid coke' are not as desirable as their lighter counterparts. Heavy oils such as bitumen and asphalt are often used in construction, road paving and in electrical power generation where they compete with coal. Heavier crudes or bottoms (residues) may be 'cracked' in order to form lighter crude. This, however, requires more capital investment and more energy to be expended in the refining process. Consequently, this reduces the value of heavier crude. Additionally, impurities such as heavy metals or sulphur will further reduce the value of the crude as it becomes more expensive to refine[9].

The crude blend, with its many different chemicals, must be separated and treated. This blend is distilled into 'fractions' using 'heat and height columns'. Temperatures can reach 350°C (662°F) in this process. This vaporises the hydrocarbons which subsequently rise to different 'heights' within a vertical column. The hydrocarbons cool down and become liquid again and are separated into fractions.

The solid residue remaining from the refinement of petroleum by the 'cracking' process is also a form of coke. Petroleum coke has many uses besides being a fuel, such as the manufacture of dry cells, electrodes, etc. Gas works that manufacture synthetic gas also produce coke as an end product called 'gas house coke'[10].

Fluid coking is a process by which heavy residual crude is converted into lighter products such as naphtha, kerosene, heating oil, and hydrocarbon gases. The 'fluid' term refers to the fact that coke particles are in a continuous system rather than in batches.

Clearly, a refinery's configuration will depend on the crude varietals it will process. In turn, this determines its configuration, processes and equipment. The list below gives an overview of standard refinery equipment:

• Desalter unit which washes out salt from the crude oil before it goes into the atmospheric distillation unit
• Atmospheric distiller or fractionating column
• Vacuum distiller which further distills the residual bottoms after atmospheric distillation
• Naphtha hydrotreater
• Alkylation equipment
• Catalytic reformer which contains a catalyst that is used to convert the naphtha-boiling range molecules

> Variations in the strength and number of inter-molecular bonds, along with impurities, determine the viscosity and the melting and boiling points of most hydrocarbon compounds.

into higher octane reformates (reformer products)
- Distillate hydrotreater unit which de-sulphurises distillate (diesel) after atmospheric distillation
- Fluid Catalytic Cracking (FCC) Unit which upgrades heavier fractions into lighter, more valuable products
- Hydrocracker unit which upgrades heavier fractions into lighter, more valuable products
- Coking unit which processes asphalt into gasoline and diesel fuel, leaving coke as a residual product
- Steam reforming unit which produces hydrogen for the hydrotreaters or hydrocracker
- Liquefied gas storage units
- Storage tanks for crude oil and finished products, and
- Utility units such as cooling towers for circulating cooling water, boiler plants for steam generation, and wastewater collection and treating systems.

Refining Efficiencies

Certain analysts and companies use 'product produced per barrel indices' and refining efficiencies as Key Performance Indicators (KPIs) of refineries. With so many variables, however, it is hard to make like-for-like comparisons. In addition, some companies may be acting as equity transfer advisors, and therefore, would have a vested interest in transacting a refining asset. Refining and marketing can offer margins; for example, in the US you can acquire stock in downstream companies (Enron was a bad example, but Premcor and Valero are good examples) that make healthy profits. This US fondness for investing in specialised parts of the oil and gas chain is catching on elsewhere. Several existing Russian and Eastern European refineries were groomed for private equity deals (and perhaps even Initial Purchase Offerings [IPOs]) which shows the confidence some people now have in refining margins)[11] .

Those profits, however, have not stacked up sufficiently to motivate investment in new refineries. Undoubtedly, one of the key contributors to heightened and more sensitive oil prices is the lack of refining capacity. Not a single new oil refinery has been built in the US since 1976 with existing plants working close to capacity. This is largely due to onerous government restrictions and permitting requirements as well as the aforementioned 'nimby' factor. As seen in 2005, hurricanes can shut down refineries causing prices to sky-rocket. As long as there is a continuing shortage of refining capacity, prices will continue to act this way. Refining is a continuous process, and should not be stopped once it has begun; however, even the most efficient plants must shut down for maintenance or for a product change periodically. By coincidence, if two or more refineries go offline at once for maintenance or a 'turnaround', it can cause a localised shortage that precipitates a price spike. Refineries try to mitigate periodic supply shortages by overproducing into storage facilities that can serve as a supply buffer during short offline periods

> Catalysts such as zeolite are commonly used to accelerate the cracking process and variations in cracking configurations exist according to the feedstock and final products required.

(see *Chapter 12: Paper Barrels—Oil and Gas Markets*)[12].

Supply Side Discussion

Today's bottlenecks of minimal spare capacity are not caused by a peak in production or because of a lack of reserves; we have seen that there are plenty of opportunities (see *Chapter 2: Peak Oil and Medieval Maps*). The problem lies with refining capacity and inventories. We have noted that most current global refining capacity is geared toward sweet and light. That refining profile is not well suited to handling the increasing volumes of sour and heavy crude coming onto the market[13]. Building new refineries to handle sour and heavy crudes seems obvious enough given the characteristics of tough-to-produce reserves. So why aren't oil companies queuing up to build new refineries?

Part of the hesitancy is explained by the bull market from 2004 up to 2008 where the highest average utilisation was 86%. Surely, however, utilisation (and profitability) for new build refineries would be even higher given their up-to-date configuration for sour and heavy? Even though the answer is probably yes, the explanation for the reluctance in building new refineries lies with market uncertainties of future demand rather than profitability, social 'nimby' attitudes against refineries and the tendency for refineries to be built in large consuming countries.

If a refinery project begins today, it takes between five to seven years before it is operational. At that time, there is no idea of where the market will be. Industry does not look favourably on idle capacity and private companies are loathe to idling[14].

This is because shareholders want healthy returns yet refining margins are notoriously difficult to get right for new builds, which do not make huge profits, and still there is the real risk of idling. Spare refining capacity, however, is precisely what the market needs to insulate it from knee-jerk reactions and maintain stable prices. That responsibility has fallen in the main part to Saudi Arabia, which has for years sought to provide a soft landing mechanism by maintaining excess production capacity, the so called supply cushion[15].

Ultimately, this is in the exporters' best interests because a prolonged period of depressed prices not only means a loss of windfall profits but giving oil away on the cheap. It can mean having the value of your most valuable resource mercilessly halved or cut even further. To illustrate, take Saudi Aramco, for example. Saudi Arabia's reserves are calculated at a high value of US $18.48 trillion at an oil price of US $70 (x 264 billion), US $13.20 trillion at an oil price US $50 and US $6.60 trillion at US $25. A sobering exercise, no doubt, but it is also worth mentioning that exporting countries are highly dependent on cashflow from oil

> There are more than 4,000 different petrochemical products, but those which are considered as basic products include ethylene, propylene, butadiene, benzene, ammonia and methanol.

revenues to keep their economies afloat[16].

That means NOCs must also keep a cash cushion when low prices swing back. Otherwise, exporters will simply have to pump higher volumes at lower prices to make up for lost revenues, if at all. That is a definite no-no in today's climate of resource sovereignty and maximising wealth.

A loss in short-term earnings and a wipe-out of the value of a finite set of reserves is not something exporters would be keen to see happen. That is why the Saudi Arabians are often called 'the voice of reason'. They want to keep markets and prices stable. They keep an eye on US inventories and check production forecasts accordingly. For exporters, an ideal rate of global economic growth is approximately one to two percent. In short, a stable scenario is one where economies grow at a manageable rate and sustain energy demand at moderate levels. Any shortfall in petroleum supply can be picked up by E & P technology gains, frontiers and growing renewables which are attractive at that price range. Lower prices and investment is pulled back.

This is a real uncertainty and much depends on how the industry will react in the next few years to say, 2011. Will it pull back investment as it appears is happening already? If so, this may simply delay the eventual supply side crunch due to a lack of new refining capacity. This could create a super spike in future oil prices. A concerted effort needs to be made to avoid this.

There is a 'paper' spanner in the works, however. We now need to consider what role the trading of paper barrels, such as oil futures, has on market volatility.

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> Fluid coking is a process by which heavy residual crude is converted into lighter products such as naphtha, kerosene, heating oil, and hydrocarbon gases.

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15. No one seems in a hurry to add refining capacity.

16. This is purely illustrative as it assumes full recovery rate, no consideration of lifting costs. Different assumptions would yield different final estimates. For example, assumptions based on worldwide oil scarcity would drive the number up, while assumptions based on rapid conversion to sustainable energy sources would drive the number down. World Energy Outlook 2008, published by the International Energy Agency.