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2013 – Issue 34

# Saudi Arabia oil & gas

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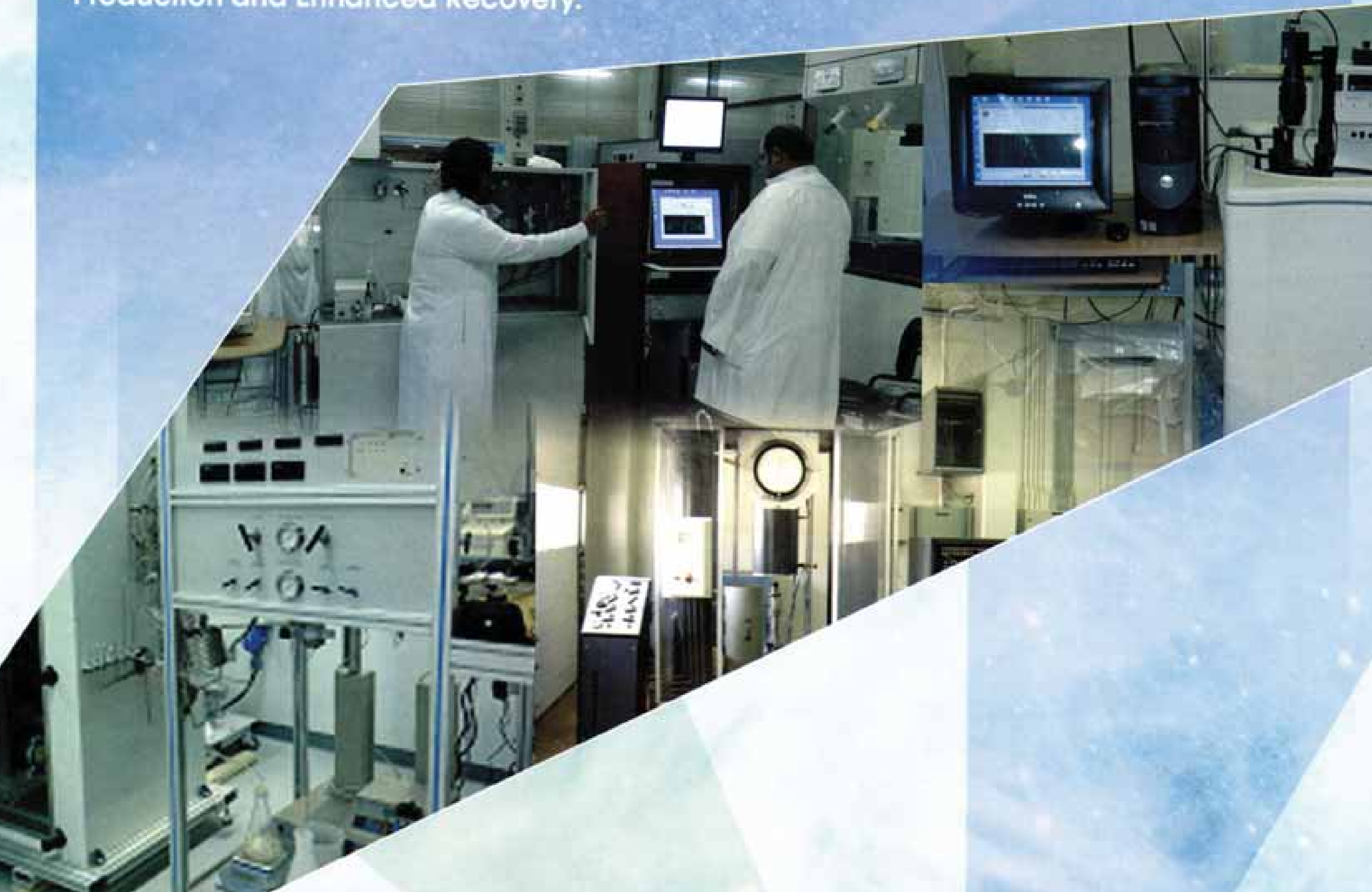
# Oil and Gas Research Institute

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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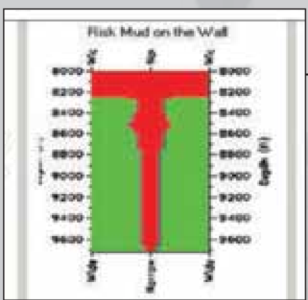







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# Building Marine Habitats

DHAHRAN, 12 September 2013 – Saudi Aramco's Environmental Protection Department (EPD) is embarking upon a major reef restoration program throughout the northwestern Arabian Gulf.

"Over the past couple of decades, there has been a lot of impact on corals from natural events," said Ron Loughland, PhD, from EPD.

"This has mostly been to do with sea surface temperature rising. The Arabian Gulf corals were in good shape up to about 1996, but then there were two incidents that changed the game."

Loughland said that a combination of extreme sea surface temperatures and increased summer wind velocities resulted in the warmer surface waters being mixed to depths as far down as 12 meters to where the corals exist. This caused widespread bleaching and the death of corals, and the eventual collapse of many reef systems.

Extensive research data has since indicated that such high sea surface temperatures hadn't occurred around these corals in a 400-year period.

"The reefs serve as a habitat for countless species. When they collapse, there is no longer any structure, so it's a big issue for marine biodiversity," said Loughland.

"We can't do much about the temperature rises and occasional disruption of the thermocline," he added. "But what we can do is put the structure back, and that's exactly what EPD is doing."

With 60 sites already identified, EPD is now planning to submerge constructed artificial reef habitats that are set to act as nursery habitats for corals and reef associated biodiversity.

The methodology is based on sound ecological principles: create the right environment and conditions, and many of the organisms that thrived on the reefs will return – that means constructing durable artificial reef habitats to be lowered into the sea.

In phase 1, EPD identified the 60 suitable areas in the Arabian Gulf where corals could exist by measuring temperature, sediment content, light infiltration, proximity to other reefs and other water quality criteria.

Phase 2 now involves designing the reefs to attract fish and other reef species, and getting the design right is a critical factor for the program.

“We came up with a design that had independent colonies, so no one species of fish can dominate. We want different kinds of fish and reef organisms to thrive,” said Loughland.

“Reefs are of different sizes and designs. At Abu Ali Island, the design we have incorporates many different reef modules and has different complexities. It is going to be the test site, and we will monitor it for a year and see what aspect of the reef modules works best. We can then roll out a final design across all the other sites.”

“We are planning for these structures to be in place for 200 to 300 years, so it’s important to get it right,” added Loughland.

Abu Ali Island is ideally located as a test location, positioned halfway between the northernmost and southernmost sites.

It will receive the first, largest and most complex prototype reef, with all remaining sites receiving similar reef colonies based on a design derived from the Abu Ali Island results.

Phase 3 of the project will then involve long-term monitoring of the new reefs, with detailed analysis and recording of coral recolonization and associated increases in biodiversity.

For more than 40 years, Saudi Aramco has been involved in marine research, including coral reef monitoring, with the Research Institute at King Fahd University of Petroleum and Minerals.

“It’s like a doctor observing a medical patient,” said Loughland. “If the patient is being monitored and his health declines, then the doctors intervene. That’s exactly what we’re doing.

“Others in the region don’t have access to data that goes that far back. The fact that we started our research some time ago indicates the company’s commitment and the importance and real value of research and data collection; this is a great example.”

And for Loughland, the whole project – like many others carried out by EPD – is another example of the company leading by example.

“This is all part of our desire to be good stewards of the environment. Our mangrove campaign focuses on coastal restoration, and this project is geared towards marine restoration. We’ll do whatever it takes to protect and enhance the productive marine environment of the Gulf as it is vital for the future wealth and food security of the Kingdom.”

# SATORP Reaches Major Milestone

JUBAIL, 03 October 2013

On October 3 the Saudi Aramco TOTAL Refining and Petrochemicals Company (SATORP), a joint venture between Saudi Aramco and France's TOTAL, launched the first shipment of its fuel oil production from King Fahd Industrial Port (KFIP). Saudi Aramco lifted this fuel volume, while TOTAL will lift a volume of diesel soon.

SATORP's chairman, Saudi Aramco's vice president for Engineering Services, Samir Al-Tubayyeb, expressed his delight at the first shipment from the SATORP refinery, which will play a major role in supporting the Kingdom's economy through production of refined petroleum products and petrochemicals.

"This joint venture between Saudi Aramco and TOTAL will generate added value to the local economy through creating jobs and providing local contractors with opportunities for further downstream investments. The refinery is expected to create 1,200 direct jobs in the Kingdom, with each of them entailing five indirect employment opportunities." Al-Tubayyeb said.

SATORP president and CEO Fawwaz Nawwab said SATORP is one of the strategic projects for Saudi Aramco and TOTAL because it will fulfill obligations to the local and global economy. Nawwab pointed out that the refinery, among the most sophisticated and advanced in the world, is operated by quality administrative and technical personnel. It was designed with the capability to increase its capacity in the long-term.

"The return from SATORP on the local economy will not be limited to meeting increasing demand, but also creating jobs for Saudis directly and indirectly, and making products that may result in spurring new industries in the future," Nawwab explained.

> "The refinery is expected to create 1,200 direct jobs in the Kingdom, with each of them entailing five indirect employment opportunities."

In January 2009, Saudi Aramco and TOTAL began executing a contract to build and operate a world-scale conversion refinery with a capacity of 400,000 bpd of Arabian Heavy crude oil in the Jubail-II Industrial City. SATORP is owned 62.5 percent by Saudi Aramco and 37.5 percent by TOTAL, and both will market the joint venture's products.

George Moreno, SATORP's vice president for manufacturing, confirmed that the SATORP refinery will be one of the world's largest and most sophisticated, refining Arabian Heavy crude and converting it into products meeting the strictest specifications to fulfill growing demand for environment-friendly fuels.

The refinery, he added, is a full conversion refinery, which will produce large volumes of diesel, jet fuel, paraxylene, benzene and propylene. With such magnitude and sophistication, the refinery will undoubtedly be one of the wonders of the oil and petrochemical industry.

Despite the complexity of the project, environmental protection was a priority.

"SATORP is committed," Moreno said, "in all its operations and business, to maintain the health, safety and security of all its and its contractors' employees, visitors and neighbors including those in the adjacent industrial facilities or residential neighborhoods. In doing so, SATORP guarantees that its employees work in a safe environment and perform their jobs to the highest levels of quality. We achieve all this through implementation of best practices and technologies, taking into consideration the preservation of the natural environment in which we all live and work."

SATORP's vice president for Human Resources and Services is Mohammed Fahd Al Otaibi, a 32-year veteran of Saudi Aramco. He noted that through 100 workshops, the SATORP team devised a plan to recruit the best talent from the Kingdom and the world.

"Young employees train in Saudi Aramco's Apprentice Program then gain experience by doing training assignments in refineries around the Kingdom, United States and Korea," he said. "Recent engineering graduates completed two-year technical assignments in refineries in Europe in cooperation with TOTAL."

SATORP achieved a 61 percent Saudization level, and through the contractors, additional jobs will be created as they meet Saudization obligations by training and employing local talent.

Coincidently, the first cargo from SATORP was loaded on Saudi National Day. "This gave us two occasions to celebrate," Fawwaz Nawwab said.

# Sights Set on Bright Future at MEPEC


MANAMA, Bahrain, 10 October 2013

Localization and the accelerated development of Saudi human capital and talent will be the key drivers of engineering excellence, economic diversity and sustainability in Saudi Arabia in the years ahead.

That was the overriding message at the second Middle East Process Engineering Conference and Exhibition (MEPEC) in Bahrain last week.

The Kingdom and Gulf region also stands on the cusp of a "manufacturing renaissance," according to HE Abdullatif Al-Othman, governor of the Saudi Arabian General Investment Authority (SAGIA).

The conference was held under the theme "Overcoming Future Challenges through Operational Excellence" and attracted delegates from around the world.

With Saudi Aramco as its prime sponsor, more than 1,500 delegates and oil and gas process engineering professionals attended the three-day conference that saw keynote addresses delivered by Abdulrahman F. Al-Wuhaib, the company's senior vice president of Downstream, Samir Al-Tubayyeb, Saudi Aramco's vice president of Engineering Services, and Jamal Naboulsi, chief operating officer of the Saudi Aramco Entrepreneurship Center (Wa'ed).

The conference opened with an address by HE Shaikh Ahmed bin Mohammed Al-Khalifa, Minister of Finance and Minister in charge of Oil and Gas Affairs for the Kingdom of Bahrain.

Saudi Aramco was singled out by its senior executive speakers as a catalyst for economic diversity and growth in Saudi Arabia.

Al-Othman said that there had been much talk of a manufacturing renaissance on the western side of the globe fueled by shale oil and gas production but that the Gulf Cooperation Council (GCC) countries are primed for more "tremendous job creation and long-term manufacturing growth than we are seeing in other places."

"The GCC countries," he said, "offer an unparalleled, reliable supply of gas and liquid feedstock. They provide unbeatable competitive advantages in location and logistics for exports to Europe, Asia and Africa. Meanwhile, domestic GCC consumer demand is booming."

Al-Othman said no region in the world could match the investor-friendly business and regulatory environment in Saudi Arabia.

In his keynote address, Al-Wuhaib introduced conference delegates to Saudi Aramco's Accelerated Transformation Program (ATP). He noted that Saudi Aramco is striving to transform "from primarily a purchaser of technology into a major creator of new technologies. To reach this goal, we plan to increase our research funding fivefold by the year 2020."

Al-Wuhaib added that the company is also committed to tripling its manpower in science and technology. "This expansion means an abundance of opportunity for motivated process engineers. Eighty percent of our research personnel will be stationed at our headquarters in Dhahran. The balance will staff a global network of new research centers addressed to both upstream and downstream issues," he said.

In his keynote address, Al-Tubayyeb pointed to three pillars "essential to achieving engineering excellence." He identified human resources, systems improvements and technology development as the trio of drivers for the future of the company and the Kingdom.

Al-Tubayyeb delivered his address on the first day of the conference on the theme of "Engineering Excellence Pillars and Saudi Aramco's Localization Program."

The search for young talent, he said, must be intensified and be a top priority for management, and knowledge transfer between new entrants and outgoing veterans must be enhanced.

"Our workforce constitutes the most important asset that drives our company forward in the path of engineering and manufacturing excellence," Al-Tubayyeb said.

Collaboration and partnerships at a national and global level are required to face the challenges the oil and gas industry now faces.

"Every effort should be exerted to collaborate with leading businesses, academic institutions, service companies and technology developers to exchange ideas and best practices to help drive excellence," he said.

Technological innovation, Al-Tubayyeb told the audience, is the pre-requisite for engineering and manufacturing excellence.

"The strategic intent of developing Saudi Aramco's Research and Development capabilities is aligned with an ambitious goal set as part of the ATP's 2020 vision. That is, through research and development, Saudi Aramco will deliver leadership technology and establish a flourishing knowledge economy in the Kingdom. By 2020, we want to be as well known for our innovation culture and energy research and technology development capabilities, as we are today for the success of our mega-projects in upstream and downstream operations," he said, adding that existing relationships with universities in the Kingdom should be further built upon.

# Remarks at 22nd World Energy Congress 2013

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


Daegu, KOREA, 14 October 2013 –

“It’s been three years since we met in Montreal. Now, as we gather in Daegu, the global energy industry is healthier, more dynamic, and, dare I say, more confident than ever. Indeed, those three short years have witnessed momentous change, so a chance to take stock of where we are, and where we need to go, is more welcome than ever.

To begin with, it is a tremendously exciting time to be in Korea. Korea’s industrialization, economic development, and resilience have astonished the world. Korea has become a byword for quality and innovation, admired around the globe for its cars, smartphones, and much more. And the world is embracing Korea’s culture and style.

The key ingredient has been the energy of the Korean people. And that provides the perfect backdrop to this Congress, where harnessing all the energy at our disposal will be fundamental to future success. Ladies and gentlemen, all of us in the energy industry face a historic challenge.

Today, less than one-third of the world’s 7 billion people consume more than two-thirds of its primary energy supplies. The other five billion people have

> "At Saudi Aramco, for example, we are on track to increase the average of our conventional oil recoveries to 70%, which is more than double the current world average."

varying degrees of access to supplies of modern energy, with some trapped in extreme energy poverty. But by 2050, a total of 9 billion people will aspire to a prosperous life. Knowing this, shouldn't we ensure that ready access to clean energy will be a right for all, not a privilege for a few? That is the inspirational challenge the world faces and the test we must pass as an industry. Indeed, this is echoed in the World Energy Council's latest Trilemma Report. So today , I want to explore the path to a sustainable energy future for all. And how we can rise to meet it.

Let me start with energy demand. As well as two billion additional people, the global economy will be three or hopefully even four times larger by 2050. More people and affluence mean more mobility, more urbanization, and more demand for durable and consumable goods. That in turn will drive consumption for fuels, electricity, and chemical feedstocks; and therefore energy.

But it is not preordained that demand has to rise to unsustainable levels, even if we provide everyone with sufficient energy. Improved energy intensity is our low hanging fruit and can deliver similar economic growth using considerably less energy. Setting aggressive targets on efficiency and demand management could dramatically reduce energy consumption while enabling wider access to energy, saving trillions of dollars, conserving natural resources, and improving environmental performance.

Improving efficiency in both energy conversion and widespread end-use applications is challenging, but I am pleased that many nations have already taken bold steps. In Saudi Arabia, we're no different. The Government has launched major initiatives to significantly improve the efficiency of energy end-use in a range of sectors like industry, transportation, and buildings. And also in electric power generation where we are replacing inefficient power plants and increasingly moving them to gas.

But even assuming the world lowers its future energy intensity to an optimal level, future demand will be much higher than it is today. Which begs the question: how are we going to supply that demand?

To begin with, the earth is blessed with a colossal endowment of fossil energy. Take the oil industry. We have already produced about 1.3 trillion barrels, yet proven reserves have never come down. Instead, current proven reserves of 1.6 trillion barrels, which

> “They are – that is oil and gas – the most efficient, convenient, economic, and reliable energy sources the world has ever known.”

equate to a half-century of global oil production at current rates, are at their highest level ever. And these numbers will continue to rise with increased exploration and improved recovery.

At Saudi Aramco, for example, we are on track to increase the average of our conventional oil recoveries to 70%, which is more than double the current world average. So resources are, in fact, abundant, which means the ‘Peak-Oilers’ have joined the ‘Flat-Earthers’!

I say this because, looking at the earth’s total endowment of liquid fuels, we are blessed with about 14 trillion barrels of original resources-in-place. This is divided about equally between conventional and unconventional resources, by which I mean tight oil, extra heavy liquids, bitumen, and oil shale. When the ingenuity of our scientists and engineers is applied to this massive endowment, current proven reserves have a lot of room to grow. Such reserves will be necessary to sustain rising long-term oil demand.

In fact, demand for oil in absolute terms is likely to rise by about 20 MMBD during the next two decades. That’s equal to the current production of the world’s two largest oil producers, Russia and Saudi Arabia, combined!

Likewise, the world’s current gas reserves of more than 7,000 trillion cubic feet have enormous room to grow, considering that the unconventional gas revolution has expanded the world’s technically recoverable gas resources to the range of 30,000 tcf. If we could economically recover them, they could meet global gas demand at current rates for more than 250 years!

And I am hopeful that these resources will grow even further. Because I believe the US shale revolution will spread far and wide, as many other areas of the world appear to hold enormous unconventional potential. The rush, ladies and gentlemen, is definitely on. In fact, I’m delighted to announce here today that only two years after launching our unconventional gas program in the frontier Northern Region, we are ready to commit gas for the development of a 1,000 megawatt power plant, which will feed a massive phosphate mining and manufacturing center, and drive that region’s development and prosperity.

But, ladies and gentlemen, this is just the latest example of oil and gas powering prosperity. They are – that is oil and gas – the most efficient, convenient, economic, and reliable energy sources the world has ever known.

And they will undoubtedly continue to be the crown jewels of world energy supplies well into the future.

Yet, despite their abundance, and because they are the crown jewels, we should use them prudently, efficiently, and more cleanly to secure our energy future. And we

> "... we continue to make massive investments to maintain the world's largest spare oil production capacity of more than 2 million barrels per day."

do that by leveraging them in combination with other sources like nuclear, hydro, coal, and renewables which will play an increasingly important, complementary role. Let me explain.

Starting with nuclear, its prospects have unfortunately been clouded by Fukushima. However, the inevitable massive growth in demand for electricity means that nuclear will still form a significant part of the electricity generation mix in the coming decades. Naturally, legitimate concerns about nuclear safety and the issue of spent fuel disposal need to be addressed. And I believe they will be if we bring our collective ingenuity to bear.

Turning to coal – and considering its abundance and lower costs – I believe it will always have a role in meeting energy demand as long as we invest in far-reaching technologies that will improve efficiency and environmental performance. However, coal will face stiff competition from ever more abundant supplies of natural gas, especially when considering that coal's carbon emissions in power generation are at least twice that of gas.

On top of these core energy sources, renewables will also have a role, although technical and economic hurdles remain in the way of their rapid deployment. Furthermore, the existing global energy system is massive, and will take time to transform, even as alternatives and renewables come on-stream. But progress is being made, costs are coming down, and the long-term role of alternatives and renewables is indisputable.

Let me also dispel any notion that the petroleum industry views these sources as competitors or displacers of demand. In Saudi Arabia, in fact, our vision is to turn the Kingdom into a global solar hub, and we are investing heavily in the research, development, and utilization of solar energy.

However, that doesn't mean the world can afford to provide costly subsidies on an ongoing basis at the expense of economic development and fiscal imperatives. Rather, the appropriate energy mix should be left to the market and technology to determine.

So I hope everyone leaves this Congress with a united view to the world outside: which is that all… energy… sources… will be required in the long-term. Yet meeting our 2050 energy goals will be easier said than done. Let me outline what I believe are the four key pre-requisites for success.

First, we need progressive, yet pragmatic and plausible, global energy policies.

Since all energy sources will be required, we shouldn't prematurely pick winners and losers; selectively

> "... adequate, timely, and long-term investments must be made in all energy sources to ensure sufficient supplies are safely and reliably produced and delivered to new consumers."

subsidize; set unworkable targets; or apply unrealistic regulatory and fiscal regimes. Instead, we should invest in technologies and let them mature to offer confidence in large-scale deployment and, let me stress again, allow markets to work.

Also, while the industry needs to further enhance the safety and environmental performance of energy sources, there are countless examples of well-intentioned but poorly thought-out policies having multiple, unintended consequences. Consider the undue emphasis on transportation when the 50 dirtiest electric power plants in the United States – all coal-fired – emit roughly as much $CO_2$ as half of America's entire fleet of passenger vehicles. Consider also that mandates on biofuels have caused numerous ripple effects – like higher food prices – that cannot be justified given their questionable environmental benefits on a life-cycle basis.

So policies need to be more rigorous and holistic, and I believe the World Energy Council can play a significant role here.

The second pre-requisite is that adequate, timely, and long-term investments must be made in all energy sources to ensure sufficient supplies are safely and reliably produced and delivered to new consumers. In just the next two decades, total energy investment is estimated to be in the range of $40 trillion. That's virtually the annual GDP of China, the EU, and the US combined! These investment levels are staggering and, to fund them continuously, projects will need to be profitable and bankable.

For that to happen, we need more certainty in the future direction of world energy markets, relatively healthy prices, and the pragmatic policies I discussed earlier. Market stability is also critical, and here Saudi Aramco continues to play a pivotal role. In the past two years alone, we have swung our production by more than 1.5 MMBD in order to address market supply imbalances. And we continue to make massive investments to maintain the world's largest spare oil production capacity of more than 2 million barrels per day.

But that's only one aspect of our broader investment across the value chain. As part of our drive to become the world's most integrated energy company, we have increased our annual capital budget tenfold from $4 to $40 billion in the last 10 years. In addition, we have scaled up our investment in talent, R&D and technology.

In fact, my third pre-requisite is game-changing, pace-

> "... we need all energy sources; all industry players; all governments; all academic and research institutions; and all energy bodies, working together in the global energy village."

setting R&D and technology because, as I indicated earlier, we need to recover more fossil fuels at lower costs and make them greener… make nuclear power plants safer and better dispose of their spent fuel…and enhance the economic viability and competitiveness of alternatives and renewables to unleash their full potential.

We've embraced that at Saudi Aramco, where our strategic goal is to become one of the world's leading creators of energy technologies by 2020. We are multiplying our funding for in-house R&D while forming world-class strategic alliances as part of our open network innovation model.

And to mitigate the environmental impact of fossil fuels, we're pursuing a broad-based, long-term carbon management program, targeting both fixed and mobile sources of carbon emissions. In fact, we are working with the Korea Advanced Institute of Science and Technology to investigate carbon capture as well as its conversion into useful products. That will make hydrocarbon energy more sustainable for producers and consumers alike, and it's just the sort of collaborative win-win we need to see more of.

Which leads me to my last pre-requisite: collaboration. Let's not jeopardize our chance to make history by working at cross-purposes. We must avoid this at all costs. Because, we need all energy sources; all industry players; all governments; all academic and research institutions; and all energy bodies, working together in the global energy village.

And speaking of the global energy village, if we agree that ready access to clean energy is a right for all, not a privilege for a few, then I believe this Congress should champion this goal, and ensure it becomes an integral part of the UN's future development agenda.

Ladies and gentlemen, providing adequate, affordable, and acceptable energy to 9 billion people will be the challenge of our lives, and of those who will follow in our footsteps. But it also presents us all with the most inspirational opportunity. So let us relish the fact that we are all in Daegu under one roof.

And I have no doubt that if we, like our host country, harness all the resources at our disposal, not least the remarkable ingenuity in this room and across our industry, then we too can astonish the world by achieving a sustainable energy future. And 9 billion people will have the energy they need and so rightly deserve."

# Best Practices Shared at Pipeline Conference


MANAMA, Bahrain, 7 November 2013

More than 560 professionals and 54 speakers from the gas and oil industry participated in the second International Conference and Exhibition on Best Practices in Pipeline Operations and Integrity Management held on October 20-23.

HE Shaikh Ahmed Bin Mohamed Al Khalifa, Bahrain Minister of Finance and the Minister in Charge of Oil and Gas Affairs, and Chairman of the National Oil and Gas Authority, inaugurated the conference and exhibition.

The theme of the event, for which Saudi Aramco was a platinum elite sponsor, was "Unleashing the Power of Sharing Best Practices in Proactive Pipeline Integrity Management and Technologies."

The conference featured a multitrack technical program consisting of 54 presentations in various subjects related to pipelines including design, construction, materials, offshore, operation and maintenance, repair and rehabilitation, asset integrity management, inspection, corrosion, automation and control.

A set of pre-conference technical workshops was organized on Sunday, October 20, delivered by Saudi Aramco and international experts in five important pipelines-related topics: in-line inspection, pipelines valves, microbiological corrosion, external corrosion and stress corrosion cracking.

Also, 49 companies and industry associations participated in the exhibition. Saudi Aramco participated in the exhibition that reflected the event theme: "Best Practices in Pipeline Operations and Integårity Management."

The exhibitors came from around the world, representing some of the major pipeline engineering firms and service providers.

> "The new investment in pipelines and integrity management presents a tremendous opportunity for locally based manufacturers and service providers to make our supply chain shorter and more reliable."

Abdulrahman F. Al-Wuhaib, senior vice president of Downstream, said in his keynote speech that Saudi Aramco's Accelerated Transformation Program will present opportunities to the pipeline industry. As the company continues with its oil and gas operations and produces new products, Saudi Aramco will install an impressive number of new pipelines to transport those materials.

Al-Wuhaib said that in the past decade, Saudi Aramco procured the majority of the pipelines from locally based manufacturers.

"We intend to extend this success to create more jobs and wealth in the Kingdom," he said. "The new investment in pipelines and integrity management presents a tremendous opportunity for locally based manufacturers and service providers to make our supply chain shorter and more reliable."

Engineers and workers will build these new pipelines with the latest technologies, Al-Wuhaib said. As the company expands its research and development capabilities, it will build on its strong foundation in building pipelines and conceive and design new technologies to improve operations.

He noted that the company has already earned patents for pipeline technology. Al-Wuhaib said that professionals in Saudi Aramco are in a strong position to innovate new pipeline technologies because they have the experience and are well aware of the challenges in the field.

"The best innovation often comes about not in a remote lab, but in the field with real-time conditions and experiences," Al-Wuhaib added. "Pipelines are the world's energy lifeline, and this conference will help to make them stronger and more reliable."

Abdulhakim Al-Gouhi, general manager of Pipelines, underscored the importance of the event to reinforce existing business relations and start new ones. "We are here today because we believe that we can unleash the power of collaboration and sharing best practices in proactive pipeline integrity management and technologies."

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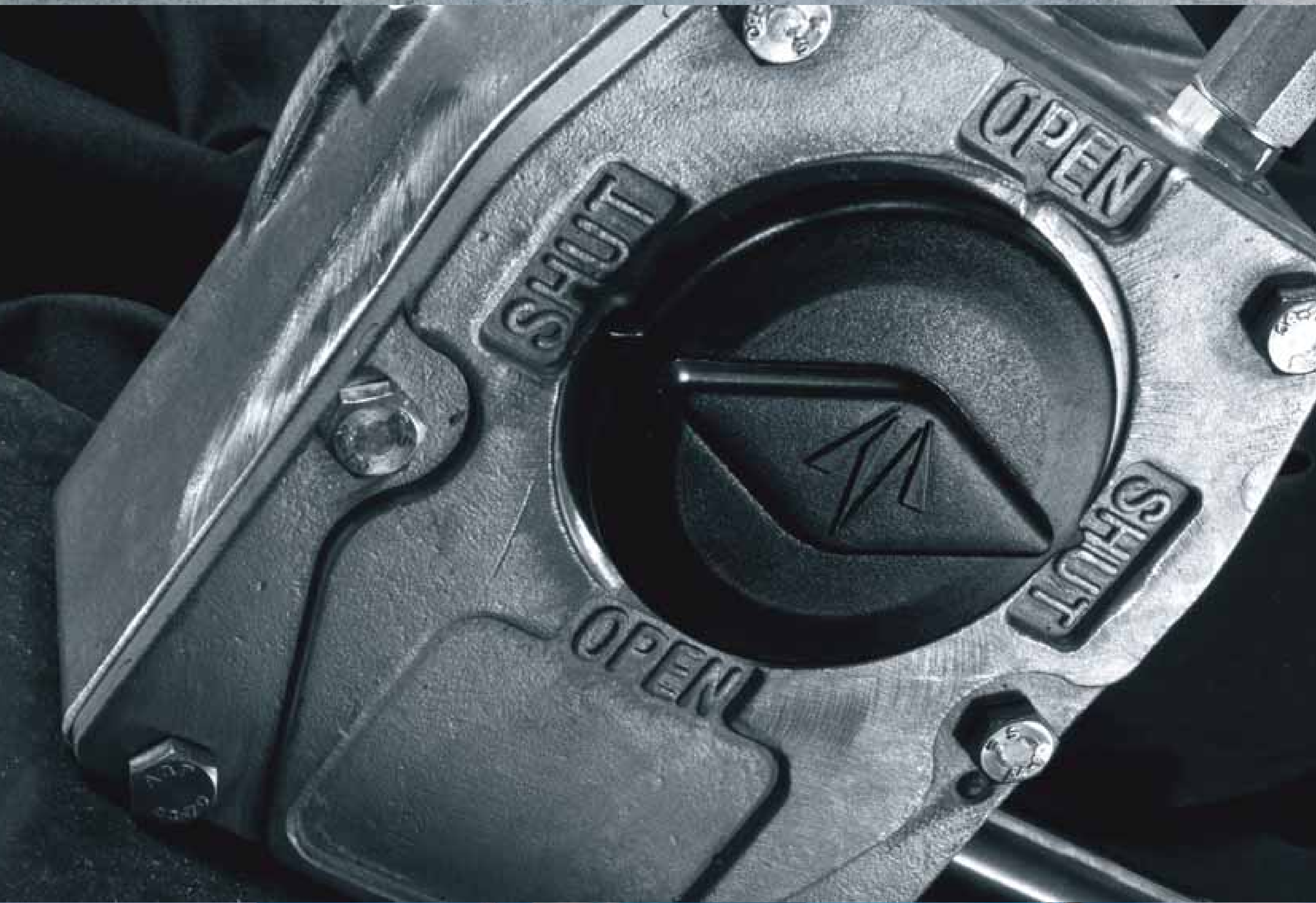


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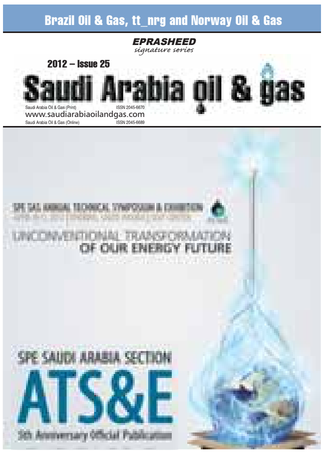








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# Evalution of Nonreactive Aqueous Spacer Fluids for Oil-based Mud Displacement in Open Hole Horizontal Wells

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## Abstract

Reactive mud cake breaker fluids in long open hole horizontal wells located across high permeability sandstone reservoirs have had limited success because they often induce massive fluid losses. The fluid losses are controlled with special pills, polymers and brine or water, causing well impairment that is difficult to remove when oil-based mud (OBM) drill-in fluids (DIFs) are used. This situation has resulted in a drive for an alternative cleanup fluid system that is focused on preventing excessive fluid leak off, maximizing the OBM displacement efficiency and allowing partial dispersion of the mud cake for ease of its removal during initial well production. The two-stage spacer cleanup fluid is composed of a nonreactive fluid system, which includes a viscous pill with nonionic surfactants, a gel pill, a completion brine and a solvent.

Extensive laboratory testing was conducted at simulated reservoir conditions to evaluate the effectiveness of the OBM displacement fluid system. The study included dynamic high-pressure/high temperature (HP/HT) filter press tests and core-flood tests, in addition to wettability alteration, interfacial tension and fluid compatibility tests.

The spacer fluid parameters were optimized based on wellbore fluid hydraulic simulation and laboratory test results, which indicated minimal fluid leak off and a low risk of emulsion formation damage. Three well trials then were conducted in a sandstone reservoir drilled with OBM in a major offshore field. All three trial wells (one single lateral and two dual laterals) treated with the displacement fluid system have demon- strated improvement in production performance. This article will discuss in detail the spacer fluids' optimization process, the laboratory work conducted and the successful field treatments performed.

## Introduction

Oil-based mud (OBM) drill-in fluids (DIFs) are favored for drilling extended horizontal wells located in reservoirs with water sensitive shale sections since they provide superior inhibition, greater lubricity, reduced mechanical friction and improved wellbore stability relative to water-based mud (WBM) DIFs. Ideally, removal of OBM cake should be done immediately after well completion to avoid long-term mud and solids aggregation in the wellbore. Residual mud cakes after wellbore displacement with solids-free OBM DIFs are relatively thinner and easier to remove at low drawdown pressures during the initial production phase[1, 2]. Nevertheless, in many other conditions, wellbore cleanup with reactive treatment fluids is required for filter cake dissolution and removal.

An effective cleanup treatment delivers optimum life cycle productivity by allowing access to the entire pay zone at a minimum drawdown pressure across the reservoir, and therefore, lowers the risk of early water breakthrough and fines migration[3]. Uniform placement of conventional breaker fluids for complete treatment

| Additive | Unit | Conc. | Property | Unit | Value |
|---|---|---|---|---|---|
| Mineral Oil | bbl | 0.52 | Density | lb/ft$^3$ | ~75 |
| Emulsifier | gal | 1.5 | Plastic Viscosity | cp | 18-20 |
| Lime | lb | 6.0 | Yield Point | lb/100 ft$^2$ | 20-25 |
| Filtration Control | lb | 6.0-8.0 | 10 sec. Gel | lb/100 ft$^2$ | 4-6 |
| Water | bbl | 0.22 | 10 min. Gel | lb/100 ft$^2$ | 8-12 |
| Organophilic Clay/Viscosifier | lb | 6.0-8.0 | Filtrate, HP/HT | ml/30 min | 1-2 |
| Organic Surfactant | gal | 0.5 | Electric Stability | volts | >800 |
| $CaCl_2$ (78%) | lb | 41 | Chlorides | mg/l | ±350,000 |
| $CaCO_3$ (fine) | lb | 90 | Excess Lime | lb/bbl | 4-6 |
| $CaCO_3$ (medium) | lb | 30.0 | Oil/Water Ratio | | 70/30 |

**Table 1. Composition and properties of OBM DIF**

of the horizontal wellbore, however, is difficult to achieve, especially in high permeability sandstone reservoirs, because of rapid fluid reaction and leak off at the first point of contact. Alternative systems, such as delayed reaction breaker (DRB) fluids, have provided only limited respite due to the rapid cake solubility associated with complete hydrolysis of esters for in-situ generated organic acid at high bottom-hole temperatures[4]. Other DRB fluids with ethylene diamine tetraacetic acid (EDTA) or its derivatives have indicated risks of reprecipitation when used in a divalent salt environment, while the inclusion of hydroxyl ethyl cellulose as a delay mechanism in DRB fluids shields calcium carbonate ($CaCO_3$) particles from the reactive fluid component and reduces the productivity performance[5]. Dual-purpose delayed cleanup fluids that are based on reversible invert emulsion DIF systems are complicated and rely on a delicate pH control to be effective[6, 7]. Current DRB fluids are also deemed suboptimal for cleanup in extended reach horizontal or multilateral wells when a noneffective mechanical isolation device is utilized with a wash pipe in the completion bore[8].

## Nonreactive Cleanup Fluids

The ideal cleanup solution for a high risk, high permeability/ fractured reservoir is an extended delay breaker fluid system that is benign at the surface but provides homogeneous treatment of OBM DIF mud cake without causing severe wellbore fluid losses during completion. The absence of such an ideal fluid has prompted the use of nonreactive aqueous fluids with a properly designed displacement process to facilitate wellbore OBM clean out and create a uniform mud cake "pinhole" prior to gradual liftoff of the residual cake during an early flow back/production kickoff operation[9, 10]. This technique is supported by previous formation damage studies, which indicate that DIF design optimization for filter cake removal via drawdown can deliver up to 95% inflow performance for gas and oil reservoirs with minimum permeabilities of 1-2 mD and 0.5-1 D, respectively[11].

OBM DIFs generally utilize CaCO3 solids as a density and bridging material. OBM filter cake and solids removal in open hole/sand screen completion wells demands the use of cleanup fluids that can disperse the oily particles and thereby enhance the residual DIF solids clean out from the wellbore. The poten- tial success of nonreactive fluids in achieving wellbore clean out is predicated on the premise that only a limited filter cake removal, albeit uniformly across the wellbore, is required for optimum well production performance. One well productivity assessment model estimates that less than 5% filter cake removal is required in a high permeability sandstone reservoir with a slotted liner completion[12-14]. The solids-free, post-cleanup displacement brine fluids will also reduce the risk of

| | |
|---|---|
| Spacer-1 | (76 pcf Weighted/Viscous Surfactant Spacer):<br><br>Mix Water + 22 ppb Viscosifier Additive + 88 ppb Barite + 2.75 gals/bbl Surfactant Additive + 0.36 gal/bbl Co-Surfactant Additive + Defoamer |
| Spacer-2 | (75 pcf Gel Spacer):<br><br>Mix Water + 0.04 ppb Specialty Additive + 0.8 gal/bbl Gel Additive + Defoamer (as needed) |
| Spacer-3 | (75 pcf Brine Spacer) |
| Spacer-4 | (62 pcf Solvent/Brine Wash Fluid):<br><br>Mix 75 pcf Brine + 40% by vol. Solvent Additive |

Table 2. Spacer fluids formulation

| Simulation Case (Viscous Push Pill) | Density | Rheology (PV/YP) |
|---|---|---|
| Base Case | 90 pcf | 25 cp/60 lb/100 ft² |
| Sensitivity Cases | | |
| Case-1 | 90 pcf | 42 cp/96 lb/100 ft² |
| Case-2 | 80 pcf | 34 cp/52 lb/100 ft² |

Table 3. Fluids displacement simulation variables

damage in wells that are suspended with low solids, oil-based DIFs/completion fluids in the wellbore long before the well is cleaned up and brought onstream.

Nonaqueous treatment fluids will not produce the desired wettability changes in the near-wellbore area, whereas conventional aqueous surfactant cleanup fluids may cause damage, which will hamper oil production if an emulsion block forms in the wellbore due to water saturation[15-17]. With the advent of microemulsion technology, nonreactive aqueous treatment fluids can be customized to achieve a relatively more effective well cleanup. Microemulsions are thermodynamically stabilized multicomponent fluids composed of oil, water and surfactant blends, which solubilize the oil component of the OBM with limited mechanical agitation[18-24]. Since acid-free micro-emulsion fluids are incapable of dissolving OBM solid particles, it is critical that dispersed residual filter cake solids are able to flow through the sand screen completion apertures when used in stand-alone screen completions. Additionally, the mechanical aspect of the displacement process must be optimal for maxi- mum removal of fluid solids in the wellbore, with final brine returns having a solids/sediments content < 1% or fluid clarity below 300 nephelometric turbidity units (NTUs)25.

## Reservoir OBM DIFs and Spacer Fluids Design Options

The predominant development oil reservoir in the field selected for the cleanup fluid trials is relatively heterogeneous with a wide variation of permeability (0.25 to 6 D) across the target pay zone section, located at a shallow total vertical subsea depth of <5,500 ft. The reservoir is a thick sequence of unconsolidated sandstone with siltstone, shale and limestone interbeds. Formation fluid is composed of medium light crude and relatively saline formation water with a maximum bottom-hole static temperature (BHST) of ~160 °F. The well laterals were drilled with a relatively

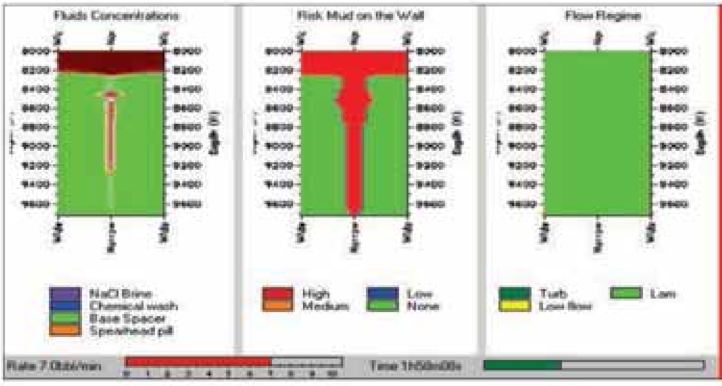



Fig. 1a. Base case flow profile (push pill displacement).

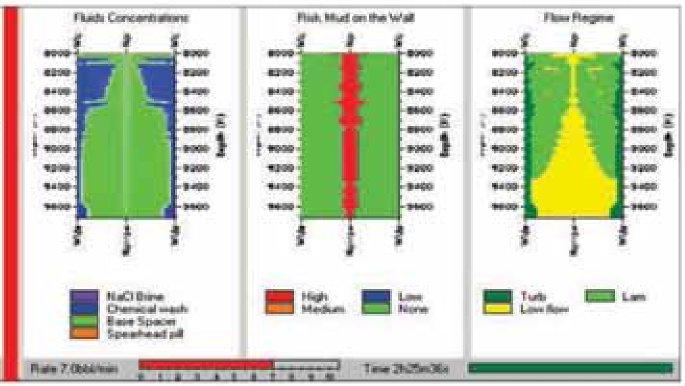



Fig. 1b. Base case flow profile (wash pill displacement).

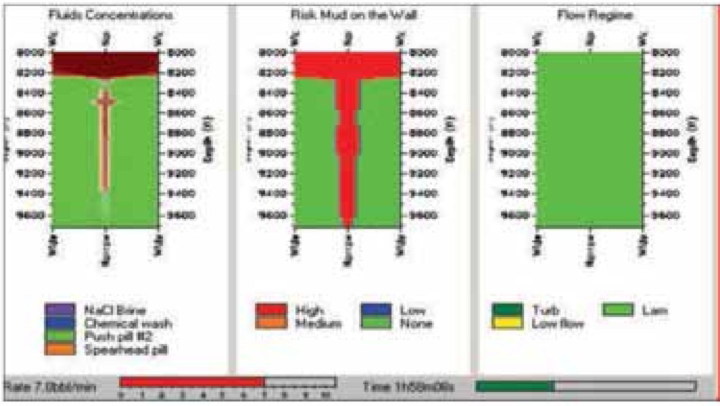



Fig. 2a. Sensitivity Case-2 flow profile (Push pill displacement).

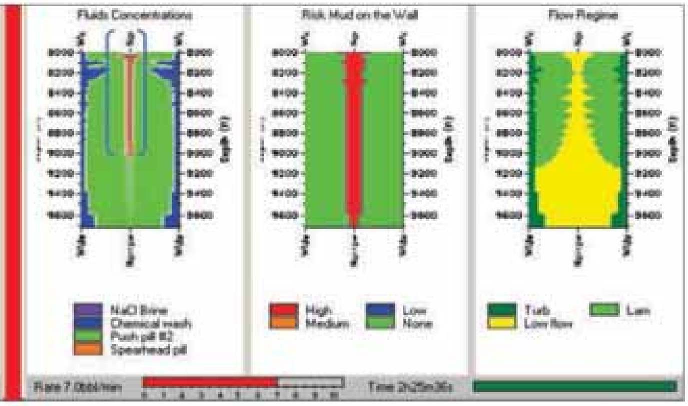



Fig. 2b. Sensitivity Case-2 flow profile (Wash pill displacement).

low density, invert emulsion OBM (75 pcf to 80 pcf, 70/30 oil/water ratio (OWR)) and completed as open hole horizontal wells with 5½" inflow control devices (ICDs)/sand screens and production equalizers installed in the 8½" lateral section (4½" ICDs/sand screens and production equalizers were used in the 6⅛" laterals for slim/sidetracked wells). The $CaCO_3$ loading required to achieve the desired mud weight was approximately 120 lb/bbl, Table 1. Previous laboratory investigation of field muds for their role in DIF induced formation damage had detected permeability reductions of 25% to 65% after mud exposure to core samples, with higher alterations recorded for higher permeability cores. Improvements observed after physical mud cake removal and core spinning down suggested that mud cake was the primary barrier to flow, while higher density (~90 pcf) muds caused additional alteration in permeability[26].

Following traditional practice, the newly drilled wells were circulated using a solids-free version of the same OBM formulated with a higher density base brine (~90 ppb $CaCl_2$) to facilitate the installation of the sand screen/completion liner assembly on the bottom. Some of the wells were subsequently left untreated for weeks and brought onstream only after production hookup facilities were installed. With the rig on-site, other wells were treated with breaker fluids, which resulted in severe losses and difficult well control situations. When there is a high risk of severe losses with breaker fluids, nonreactive aqueous spacer fluids are recommended to displace the DIFs from the well. A combination of chemical and mechanical actions by the spacer fluid system is required to achieve mini- mum damage in extended horizontal wells during cleanup[27, 28]. Criteria that effective spacer fluids must achieve in a water-based spacer and completion formulation are:

- Effective displacement of the OBM.
- No excessive losses during different displacement stages.
- Thinning and weakening of the mud cake by solubilization of the oil from the OBM and filter cake into the spacer fluid, and wettability reversal (to water-wet) for better mud cake dispersion and easier lift-off during production.

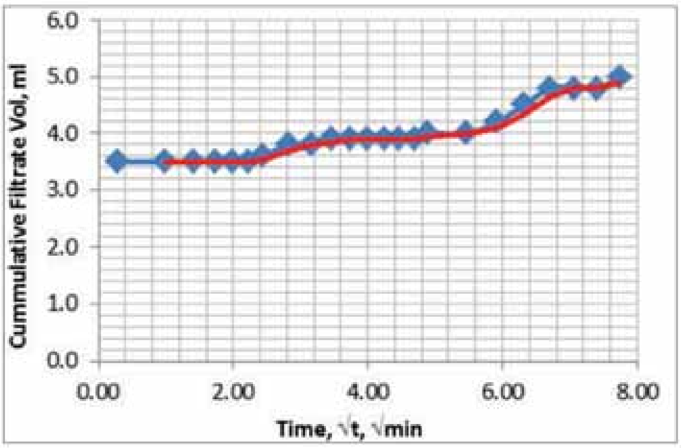



Fig. 3. OBM DIF filtrate vs. square root of time.

| OBM/ Spacer Fluid | RPM Readings | | | | PV cp | YP lb/100 ft² |
|---|---|---|---|---|---|---|
| | $\Phi_{600}$ | $\Phi_{300}$ | $\Phi_{200}$ | $\Phi_{100}$ | | |
| Field OBM | 119 | 74 | 55 | 32 | 45 | 29 |
| Lab OBM | 97 | 60 | 52 | 30 | 37 | 23 |
| Push Pill | 114 | 78 | 63 | 48 | 36 | 42 |
| Gel Pill | 73 | 58 | 51 | 43 | 15 | 43 |

Table 4. OBM and spacer fluids rheology

The aqueous spacer fluids train options considered included:

- Dispersant base oil, viscous push/gel pill, wash/surfactant pill (3-spacer fluids train).
- Viscous push pill, viscous push/gel pill, brine spacer, surfactant/solvent wash pill (4-spacer fluids train).
- Dispersant base oil, viscous push/gel pill, brine spacer, wash/surfactant pill, solvent pill (5-spacer fluids train).

Following a decision to test an acid-free microemulsion spacer fluid (MSF) system, the 4-spacer fluids train system containing a surfactant/solvent wash pill was selected. The composition and properties of the spacer train are given in Table 2. The proposed nonionic surfactants used in the above spacer system were reported to be insensitive to temperature and salinity.

**Fluids Hydraulics and Spacer Displacement Modeling**

Wellbore fluids displacement efficiency is essentially determined by the hydrodynamic properties of the OBM and the cleanup fluids, in addition to the chemical interaction of the DIFs, completion fluids and formation fluids. Wellbore fluid hydraulics analysis software was used to evaluate the fluid-fluid displacement behavior at expected downhole conditions and determine optimum cleanup fluid performance. The software applied the well geometry, fluids density and rheology data to generate different fluids flow/interface profiles at specific pump rates. Previous industry experience had identified the need for contrasts between the mechanical properties of the fluid being displaced and those of the displacement fluid to enhance the wellbore fluid's clean out[29, 30].

A base case model was developed using a spacer fluid system, i.e., a base oil, a weighted/viscous spacer (push pill) and a low weight cleaning/wash pill, which was a blend of brine and surfactants, Figs. 1a and 1b. Two sets of simulations were conducted to optimize the spacer train design parameters, such as density, rheology, fluid volume and contact times. This was required to determine which spacer train displacement process demonstrated the most displacement efficiency. The two sets of simulations also tested the sensitivity of the wellbore fluid displacement performance to the physical properties (density and rheology) of the

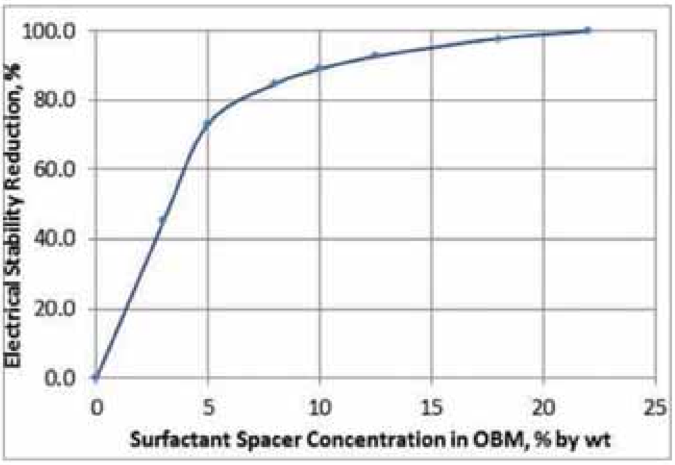



Fig. 4. Surfactant effect on OBM electrical stability.

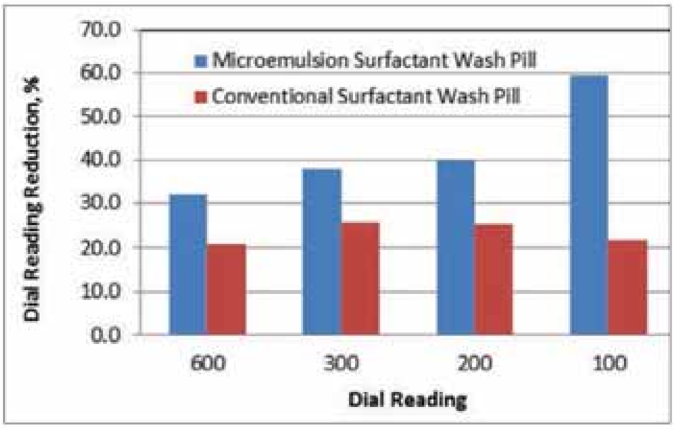
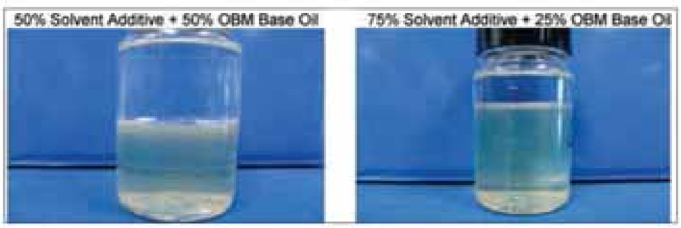
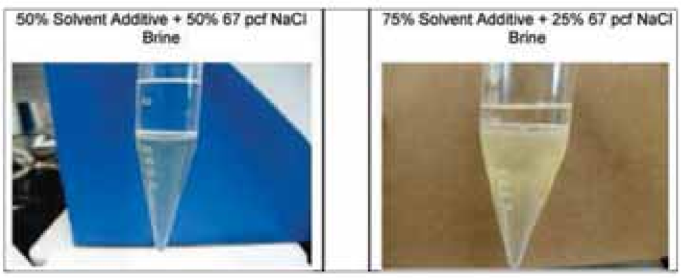



Fig. 5. Conventional/Microemulsion surfactant effect on OBM rheology.

Photos 1a and 1b: OBM DIF sample before and after surfactants at 120°F.




Photos 2a and 2b: Compatibility test of solvent pill with OBM base oil at 120°F and 1,000 psi.




**Photos 3a and 3b: Compatibility test of solvent pill with 67 pcf NaCl completion brine at 120°F and 1,000 psi.**


**Photo 4. Confirmation of Winsor Type III microemulsion using surfactant solution with field OBM sample.**

**Photos 5a and 5b. OBM sample mud cake and after cleanup flush with solvent spacer at 120°F**

key spacer (push pill) and the volume/contact time of the component spacers. Table 3 describes the varied parameters for the different case scenarios.

The simulation results reflected displacement performance for each scenario in terms of "fluid concentrations" and "risk of mud left on the wall" snapshots. The absence of visible improvement with higher rheology spacers (Sensitivity Case 1) and the significantly poorer mud removal observed at lower density (r = 80 pcf) (Sensitivity Case 2) indicated that the density difference is a more dominant factor than the rheology difference, Figs. 2a and 2b. The second set of simulation results also showed that increasing the volume of the high density push pill relative to that of the wash/cleaning pill gave improvement in the cleanup. It was noted that the key spacer fluid/push pill was unable to remove bulk mud from the nar-

| Fluid Interface | IFT Measurement |
|---|---|
| Water: OBM | 48 |
| Solvent/Wash Pill-A: OBM | 0.160 |
| Solvent/Wash Pill-B: OBM | 0.078 |

Table 5. Results of IFT tests at 70°C

| Spacer | $W_1$, g | $W_2$, g | $W_3$, g | FCR% | $T_i$, mm | $T_f$, mm | Reduced Cake Thickness, % |
|---|---|---|---|---|---|---|---|
| Solvent Pill | 45.99* | 56.36 | 54.451 | 18.41 | 9.57 | 8.89 | 7.11 |
| Surfactant | 52.581 | 57.97 | 57.491 | 8.89 | 9.28 | 9.04 | 2.56 |
| Cleanup Flushes | 53.743 | 62.281 | 60.520 | 20.63 | 10.03 | 9.38 | 6.48 |
| *10 micron ceramic disk | | | | | | | |

Table 6. Results of the filter press tests

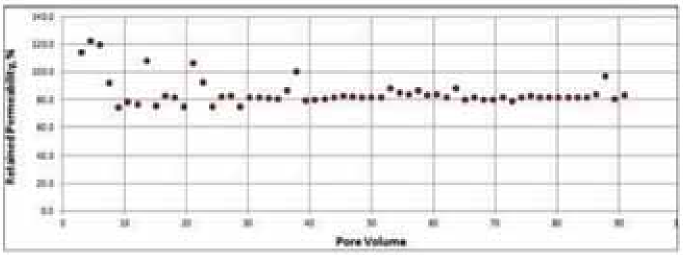


Fig. 6. Retained permeability vs. pore volume of cleanup treatment fluid.

row side of the open hole section in all cases at a poor pipe standoff of ≤50%. These simulation results were instrumental in altering the push pill density to 90 pcf, which led to improved performance in subsequent spacer fluid applications.

## Experimental Studies

### HP/HT Filter Press and Rheology Tests

A fluid loss performance test carried out with a HP/HT filter press on the field OBM DIFs indicated a minimal fluid loss at static conditions with a 35-micron ceramic disc at 140 °F (total filtrate volume ~5.0 ml after 60 minutes), Fig. 3. Table 4 shows the rheology for the laboratory OBM, field OBM and key spacers, with the field mud showing higher rheological values due to the additional solids accumulated during the drilling process. The push pill designed in this work showed a favorable yield point (YP) in contrast with the conditioned DIF (similar to the lab DIF) and field OBM before commencement of the cleanup operation. The YP value of the key displacing fluid (push pill) was approximately 1.5 times the YP for the displaced OBM (laboratory and field), as recommended by Javora and Adkins[30].

The dispersion effect of the surfactant/solvent wash pill on the OBM was evaluated by measuring the change in the emulsion stability and rheology of the OBM when it was mixed with different volumes of the wash pill. This change in emulsion stability and rheology was measured using an electrical stability meter and a viscometer, respectively. Figure 4 shows the increased reduction in electrical stability achieved by increasing the mixing ratio of the surfactant spacer with the OBM. At around 12 wt% of wash pill added to the OBM, a reduction of 90% in emulsion stability was measured.

| | Test Well-1 | Test Well-2 | Test Well-3 | |
|---|---|---|---|---|
| | | Upper Lateral | Upper Lateral | Lower Lateral |
| Stage-1 | | | | |
| Weighted Spacer | 60 bbl | 60 bbl | 60 bbl | 60 bbl |
| Gel Spacer | 60 bbl | 60 bbl | 60 bbl | 60 bbl |
| Brine Spacer | 60 bbl | 60 bbl | 60 bbl | 60 bbl |
| Solvent Pill | 45 bbl | 35 bbl | 35 bbl | 40 bbl |
| Displacement Brine (75 pcf) | NA | 350 bbl | 390 bbl | 380 bbl |
| Gel Spacer* | NA | 70 bbl | 70 bbl | 140 bbl |
| Stage-2 | | | | |
| Weighted Spacer | 30 bbl | 30 bbl | 30 bbl | 30 bbl |
| Gel Spacer | 30 bbl | 30 bbl | 30 bbl | 30 bbl |
| Brine Spacer | 30 bbl | 53 bbl | 40 bbl | 67 bbl |
| Solvent Pill | 35 bbl | 45 bbl | 40 bbl | 35 bbl |
| Displacement Brine** (2-3 hole volumes until clean returns) | 75 pcf $CaCl_2$ Brine | 75 pcf NaCl Brine | 75 pcf NaCl Brine | 75 pcf NaCl Brine |
| *Spotted in open hole prior to stinging out of the sand screen PBR<br>**Displacement after setting production packer | | | | |

**Table 7. OBM spacer fluids pump sequence and volumes**

| | Test #1 | Offset #1 | Offset #2 |
|---|---|---|---|
| Date | Feb. 2010 | Aug. 2007 | Jan. 2002 |
| *Prod Rate % | 110 | 41 | 100 |
| Water Cut % | 5.0 | 59.1 | 36.3 |
| | Test #2 | Offset #3 | |
| Date | June 2010 | Feb. 2008 | |
| *Prod Rate % | 157 | 100 | |
| Water Cut % | 0 | 4.3 | |
| | Test #3 | Same offset well with Test #2 well above | |
| Date | June 2010 | | |
| *Prod Rate % | 145 | | |
| Water Cut % | 0 | | |
| *Compared to offset wells with acid cleanup and severe losses | | | |

**Table 8. Well production performance of test well and offset well**

**Photos 6a and 6b. Displacement brine returns after first-stage treatment and after second-stage treatment.**

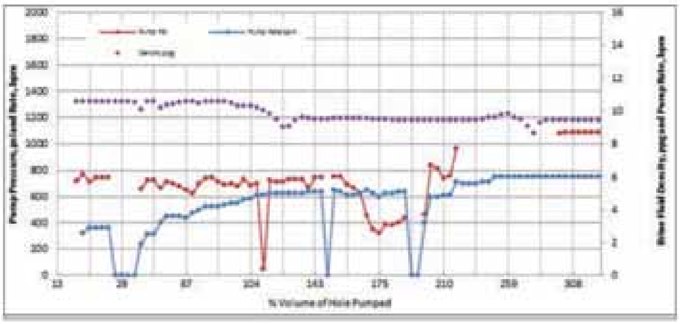


**Fig. 7. Pump and displacement brine data for lower lateral in test Well-3**

This reduction is an indication of how well the wash pill was dispersing the OBM and reversing the wettability to more water-wet. A complete dispersion of the mud components in the wash pill was accomplished at a concentration of 20 wt%.

Figure 5 shows the change in viscometer reading that was caused by the addition of 10% vol/vol of the wash pill to the OBM at speeds ranging from 100 rpm to 600 rpm. The microemulsion surfactant wash fluid reduced the OBM rheology by 30% to 60%. Measurement of the rheology of the OBM and spacer fluid mixtures was required to determine the fluid's behavior at the mixing zone/interface during wellbore displacements. The test also enabled performance comparison of different surfactants or surfactant concentrations on specific OBM DIFs.

## Compatibility/Wettability and Interfacial Tension Tests

A bottle test was performed to confirm the ability of the surfactant/wash pill to water-wet the OBM particles. Tests that simulated the OBM/surfactant solution interaction were prepared with an OBM/solution ratio of 10/90 that was left to soak overnight at ~120°F. Visual observation of solid particle dispersion, with none of the particles sticking on the glass, gave an indication of the cleaning effectiveness. Mud particles were fully dispersed and water wetted for the mixed solution, Photos 1a and 1b. See-through cell tests were also carried out to assess the compatibility of the solvent additive with the OBM DIF base oil by observing the mixed fluids at different ratios of 25/75, 50/50 and 75/25, Photos 2a and 2b. Similar compatibility tests were carried out between the solvent and the base brine, Photos 3a and 3b. No precipitation or emulsion droplets were observed for the different fluids at bottom-hole conditions, i.e., a circulating pressure of 1,000 psi and a temperature of 120°F. A Winsor Type III middle-phase microemulsion was also confirmed after mixing the OBM with a surfactant/solvent wash pill, Photo 4.

An inter-facial tension (IFT) test was conducted on the surfactant based wash pill/OBM fluid system, using the spinning drop method for measuring ultra-low IFTs to determine the effectiveness of the surfactant solutions in solubilizing the oil in the aqueous surfactant based solution and in water wetting the OBM filter cake. This test followed from the established fact that cleaning of oil and oily dirt from solid surfaces with surfactant solutions is largely dependent on ultra-low IFTs (<< 1 μN/m = 1 dyne/cm) between the immiscible fluids. Table 5 shows two different surfactant/solvent solutions that gave relatively low IFTs with the OBM at 70°C (158°F), i.e., 0.160 and 0.078 dynes/cm as against the ~48 dynes/cm expected for a typical water/oil fluid interface. Also, the surfactant/solvent solution was completely haze-free, indicating salinity tolerance at the test temperatures.

**Performance of Cleanup Flush/Circulation Treatment**

To study the ability of the spacer train to thin and weaken the filter cake while maintaining minimum fluid losses during the wellbore clean out, a filter press test was conducted on the cleanup spacers using a synthetic ceramic disc of the permeability range, 35.0 µm, (equivalent to 10 Darcies) and OBM DIFs at expected reservoir conditions. OBM filter cake was prepared by circulating the mud for 30 minutes at an expected overpressure of 500 psi and a bottom-hole circulating temperature of 140°F, followed by 3 hours of static conditions. The spacer fluids were circulated sequentially, one after the other, on top of the filter cake, with dynamic conditions at 350 psi and 140°F. Filtrate volume was monitored during the circula- tion of each spacer, and the total fluid leak off (TFL) after the circulation treatment was recorded. The thickness and weight of the mud cake were also recorded before and after the cleanup flush treatment, and the percent filter cake reduction (FCR) was computed.

It was observed that the solvent wash pill altered the wettability of the mud cake and OBM particles, changing from oil-wet to water-wet after circulation treatment. Also, it was shown that the wash pill thinned the mud cake and reduced its weight, Photos 5a and 5b. The results showed a maximum TFL < 30 ml (~20% of treatment fluid) and a FCR of ~10% to 20% with optimized spacer fluid formulations after repeated tests at expected operating conditions, Table 6.

**Coreflood Tests**

Coreflood tests were conducted to determine the return permeability using different spacer trains in a dynamic fluid loss instrument with two test cells. The tests were conducted at a third-party laboratory facility using these procedures:

• Base Permeability Measurement: Cores were loaded into the test cells, and the flow of mineral oil was initiated in the production direction to obtain initial core permeability at 150°F.

• Dynamic Fluid Loss Measurement: Mud was loaded into the system, and the pump was started at a predetermined shear rate that matched the wellbore flow conditions. Differential pressure across the cores was 350 psi while system temperature was maintained at 150°F, with fluid loss lines opened for 4 hours.

• Static Fluid Loss Measurement (pump shutdown): The mud differential pressure across the core was reduced to 250 psi while the system temperature was increased to 150°F, with fluid loss lines opened for 2 hours.

• Cleanup Flush/Circulation Treatment: Two different cleanup spacer fluids trains were circulated with the differential pressure across the two cores maintained at 350 psi.

• Final Permeability Measurement: Mineral oil was again initiated in the production direction at the same bottom-hole conditions used for the base permeability measurement above.

The proportional retained permeability computed for the two spacer fluids trains enabled the selection of the superior surfactant/solvent wash formulation with acceptable retained permeability (> 70%), Fig. 6. The selected spacer train was composed of nonreactive components, i.e., nonionic surfactant, gel pill, sodium chloride (NaCl) completion brine and solvent pill.

## Field Application and Case Histories

**Test Well-1**

The well was originally drilled and completed as a deviated cased hole/perforated completion across the target reservoir (7” casing was cemented from total depth to the surface) in 1984. The well was subsequently sidetracked using a 75 pcf diesel oil-based DIF and thereafter completed with a 4½” sand screen and ICDs on the bottom after sidetracking and cementing a 4½” casing off the bottom inside a 7” open hole in July 2009.

The two-stage cleanup wash with a 4-spacer fluids train was carried out as planned in August 2009, Table 7. The post-completion production test indicated a production increase of 10% (5% water cut) compared to offset wells in the area. Well performance was better, with a 60% higher production rate compared to an offset well that had experienced severe fluid losses during breaker fluid treatments at a similar well completion stage, with those losses controlled using killing fluid, Table 8.

**Test Well-2**

The dual horizontal well was drilled with 75 pcf to 80 pcf mineral oil-based DIFs and completed with a 5½” ICD/sand screen in the lower lateral and a 4½” ICD/sand screen in the upper lateral in July 2009. The 3,440 ft lower lateral was treated with 200 bbl of a reactive microemulsion/mesophase fluid system due to the unavailability of the spacer fluid additives. The treatment fluid was formulated with NaCl brine/ 10% acetic acid and nonionic surfactant additive (displaced and spotted in open hole with 125 bbl of 70 pcf NaCl brine).

The 3,300 ft upper lateral cleanup was carried out using acid-free MSFs in two stages with NaCl brine as the displacement fluid in July 2009, Table 7. The initial displacement rate was limited at <1.2 bpm with maximum pressure at 700 psi during treatment of the upper lateral to avoid premature packer setting. The post-completion production test indicated a 157% (0% water cut) production rate when compared with the offset well. Well performance was better than that of the offset wells that had encountered severe fluid losses while being treated with breaker fluids during completion, Table 8.

**Test Well-3**

The last test well had a hole configuration and completion design similar to that of test Well-2, but both laterals were cleaned out with the microemulsion fluid system in August 2009. A two-stage cleanup wash with a 4-spacer fluids system was carried out prior to completion brine displacement and circulation in both laterals. For the 6⅛" upper lateral (~2,540 ft), initial displacement was maintained at <1 bpm with maximum pressure at 800 psi to avoid premature packer setting. Similarly, the initial displacement was kept below 5 bpm for the lower lateral (~3,180 ft), Fig. 7.

Brine samples were collected on the surface after the first-stage and second-stage cleanup followed by displacement brine to assess the performance of the well cleanup operation. Extensive analysis of the brine returns after more than 200% hole volume displacement indicated adequate removal of the solids or sediments contained in the wellbore (less than 0.3% solids content was recorded for the test Well-3 upper lateral), Photos 6a and 6b. The post-completion production test indicated a production rate of 145% (0% water cut) compared to the same offset wells used for the test Well-2 assessment. The well performance was appraised as better than that of the offset wells that had breaker fluids treatment while encountering severe losses at completion, Table 8.

## Conclusions

1. Reactive mud cake breaker fluids are incapable of effectively removing OBM filter cake in long open hole horizontal wells located across high permeability sandstone reservoirs without inducing severe fluid losses and emulsion induced formation damage as a result of the OBM, completion and formation fluids mixing together.

2. A two-stage circulation treatment with acid-free MSFs has been proven effective in facilitating open hole sandstone wellbore cleanup by altering the wettability of the oily filter cake and mud particles without completely removing the filter cake and so inducing fluid losses that need to be controlled with more damaging materials.

3. It is recommended to evaluate the probability and potential risk of severe losses with breaker fluid application to the filter cake by reviewing the completion and cleanup fluid performance in offset wells prior to using the acid-free MSFs.

4. The surfactant/solvent fluids were effective in dispersing and water-wetting the OBM DIFs. The OBM base oil and formation brine were found to be compatible with the sur-actant/solvent pills as no precipitation or emulsion was observed at bottom-hole conditions. The generation of a Winsor Type III middle-phase microemulsion was confirmed.

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## Biographies

Peter I. Osode is a Petroleum Engineer Specialist with the Formation Damage and Stimulation Unit in Saudi Aramco's Advanced Technical Services Division.

He has over 30 years of diverse upstream industry experience spanning wellsite petroleum engineering operations, production technology (well and reservoir management, production optimization and production chemistry) and drilling and completion fluids management. Peter started his career with Baroid/Halliburton as a Technical Sales Engineer before moving to Shell Petroleum Development Company in Nigeria and Shell International's affiliate-Petroleum Development Oman (PDO) in Oman. He has participated in a number of Shell Global E&P Well Performance Improvement projects and was the subject matter expert on drilling fluids performance assessment process prior to joining Saudi Aramco in 2009.

Peter received his B.S. degree with honors in Petroleum Engineering from the University of Ibadan, Ibadan, Nigeria.

He is an active member of the Society of Petroleum Engineers (SPE) International and has authored a number of published technical papers. Peter is currently involved in formation damage evaluation of reservoir drilling and completion fluids.

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Msalli was a principal member of the focused team tasked with promoting innovation in Saudi Aramco through the development and launching of the first Innovation Tournament (InTo) in 2010. He has been an active member in the Society of Petroleum Engineers (SPE) by publishing seven technical papers and leading the Young Professionals (YP) and Students Outreach committee of the SPE-Saudi Arabia Section (SAS) for 2010/2011. Also, Msalli served as the 2010/2011 SPE-SAS representative on the North Africa and Middle East (MENA) YP committee.

He received his B.S. degree in Chemical Engineering from Louisiana State University, Baton Rouge, LA, in 2005. In 2011, Msalli received his M.S. degree in Chemical Engineering from KFUPM. He is currently pursuing his Ph.D. degree in Petroleum Engineering at the Colorado School of Mines, Golden, CO.

Khalid H. Bin Moqbil started his petroleum engineering career in Saudi Aramco's Exploration and Petroleum Engineering Center – Advanced Research Center (EXPEC ARC) in 2005. His area of interests include studies in formation damage related aspects of reservoir drilling, completion and well stimulation fluids in addition to water injection studies.

Khalid is currently working with the Gas Reservoir Management Department where he is involved with gas production optimization and reservoir management projects.

In 2005, Khalid received his B.S. degree in Chemical Engineering and in 2011, he received his M.S. degree in Petroleum Engineering along with a graduate certificate Smart Oil Field Completions, all from the University of Southern California, Los Angeles, California.

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Khaled A. Kilany has over 25 years of industry experience while working as a Reservoir and Production Engineer. He started his career in the oil fields as a Production Engineer working from 1986 to 1990, and then Khaled switched to reservoir engineering, working as a Reservoir Simulation and Reservoir Management Specialist in several international companies in Egypt, Canada and the Gulf area, including AGIP in Egypt, the Kuwait Oil Company and Shell International in Canada and Oman prior to coming to Saudi Aramco.

Since joining Saudi Aramco in August 2005, Khaled has worked as a Senior Reservoir Engineer with the Northern Area Reservoir Management Department where he was involved in introducing innovative completion equipment and production optimization techniques in Safaniya field. Khaled's experience here includes his participation in several reserve assessment studies, short- and long-term production forecasts, waterflood management and full field development plans. He currently leads a sub-team of the Manifa Incremental Project Team that is tasked with the largest ongoing offshore incremental development project in the company.

In 1982 Khaled received his B.S. degree in Petroleum Engineering from Cairo University, Giza, Egypt.

Eddy Azizi has over 17 years of experience that consolidates his current position as Senior Production Engineer within the multidisciplinary Northern Area Production Engineering team in Saudi Aramco. He has worked in both offshore and onshore environments at both Shell International and Saudi Aramco. Eddy started his career in the oil field as a Process Engineer for 2 years, and then worked as a Well Site Drilling/Completion Engineer for 2 years and one year as a Well Services Supervisor in the field. He later worked as a Production Technologist and/or Production Engineer for the next 12 years with involvement in several field development assessment studies/plan, short- and long-term production forecasts, sand management, production system modleing/nodal analysis and ESP operations and unconventional oil production systems.

Eddy has been involved in a number of new production optimization initiatives, which has resulted in improved stimulation fluid placement, zero flaring, and completion integrity management in addition to reduced coil tubing utilization in Safaniya while he currently leads the Well Integrity team working on the Qatif field.

Eddy received his B.S. degree (First class honors) in Chemical Engineering from London University, London, U.K., in 1995.

# Lessons Learned from Water Shut-off of Horizontal Well Using Inflatable Packers and Water Shut-off Chemicals in the Ghawar Field of Saudi Arabia

By Hemant K. Sharma, Jorge E. Duarte, Mufeed H. Eid, Turki F. Al-Saadoun and Jose R. Vielma.

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## Abstract

Due to the advancement of technology and improved capabilities of drilling horizontal wells, producers and injectors are now commonly completed with long horizontals to expose large reservoir areas. For the reservoir pressure maintenance, the most prevalent means is by using water injection. This injected water, while helping in pressurizing the reservoir, becomes a curse when it starts to produce with the oil. In addition, as the transmissibility of the water is higher than the oil, water breakthrough is a major challenge facing the oil industry. Various techniques are available and being used worldwide to control/reduce this produced water; however, controlling water production by performing water shut-off (WSO) in horizontal wells is more complicated and challenging than in vertical wells.

To control water production in horizontal wells, isolation of the wellbore using inflatable packers in open/ cased hole completions and capping with cement has shown little success in the past.

Therefore, another technique was attempted to control water production in horizontal oil producers by using mechanical means to isolate the wellbore and chemical means to isolate the matrix/fissure, which forms a permanent barrier and reduces water production. Determining the selection criterion for mechanical isolation and the type of chemical suitable for the formation is a tedious task for the petroleum engineer. Most of the time, the available vendor's data being used and applied to the field application, shows a low success ratio.

In this article a brief overview has been presented, taking into account two wells from the Ghawar field in Saudi Arabia, where a combination of wellbore isolation using inflatable packers and matrix/fissure isolation using an organically cross-linked polymer (OCP) system were performed. The candidate selection criteria, job criteria, planning, execution, and post-job evaluation will be discussed.

## Introduction

Unwanted water production is one of the major chal- lenges being faced by the oil industry. Since the trans- missibility of the water is higher than oil, water tends to become the dominant produced fluid as the hydrocarbon field matures. It is estimated that around 210 million barrels of water is being produced on a daily

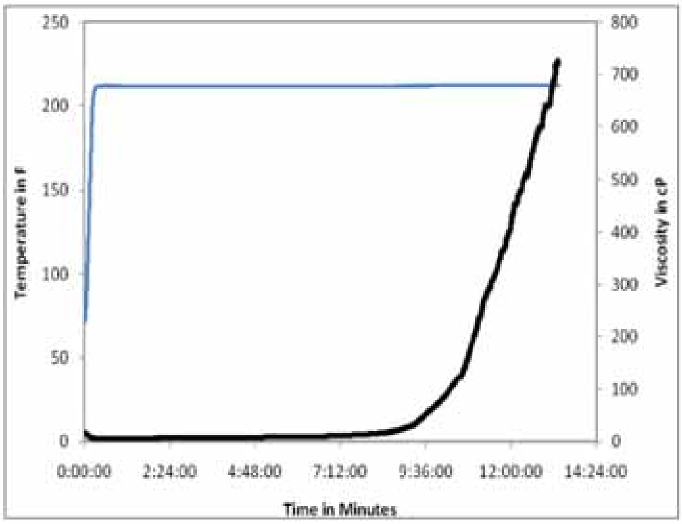


**Fig. 1. Lab test for setting time for OCP system using Model 50 Rheometer at 212 F (High viscosity start to develop after 9 hours).**

basis along with 75 million barrels of oil worldwide, needing an investment of $45 billion each year for its disposal and other environmental issues[1]. In addition, the loss of revenue due to decreased oil production in many cases adversely affects the well economics. Sometimes the producing zones included are abundant in an attempt to avoid excessive water production, even when the intervals retain large volumes of recoverable hydrocarbons.

In a hydrocarbon reservoir the natural fractures are considered to be a blessing as the oil production is greatly enhanced due to the increased permeability and enhanced reservoir contact, but the same becomes a curse when the natural fractures are connected with the water zones. If these zones contain high mobile water saturation, they soon will impact the productivity of the hydrocarbon zone. Early water breakthrough caused by edge water flowing through faults is another associated common problem[1].

Remediation techniques for controlling the water production, generally referred to as conformance control, includes the use of various means, such as mechanical, chemical, or both[2-5]. Isolation of the wellbore using inflatable packers and or inflatable bridge plug (IBP) and capping with cement is one of the most common techniques being used in the oil industry for controlling the water production for vertical wells. Recent information on oil-water contact and the presence of natural barriers are two important considerations for the production engi- neers to consider during the design of the treatment. The same task for the horizontal wells are much more complex as the horizontal permeability is many times higher than the vertical permeability and the water can bypass the isolated zone and become the dominant produced fluid within a few days.

To control water production in horizontal wells by creating an artificial barrier, a gel system based on a low molecular weight polymer cross-linked with organic cross-linked polymer (OCP) was considered. The principle of operation is to pump the OCP system into the formation around the wellbore and then propagate it through the rock matrix into the water producing zone. With temperature and time a gelation reaction takes place in-situ, forming a highly viscous gel. The three dimensional geostructure plugs pore spaces and channels and thereby limits undesired water flow. Cross-linkers were developed to delay the increase in viscosity with time due to increased temperature of the formation. Delaying the action of the cross-linkers improved the friction pressures (avoid having to pump a highly viscous fluid because the resulting high surface pressures could end up in not being able to pump into the matrix); it also lowers the polymer load and minimizes shear degradation. A permanent barrier strategically placed only in the water zone is formed because the oil and gas producing zones can be mechanically isolated[3-5].

## OCP System

The OCP system was selected based on these advantages[2-5]:

1. Low-viscosity fluid system: A thin fluid system that can be easily injected deep into the matrix of the formation

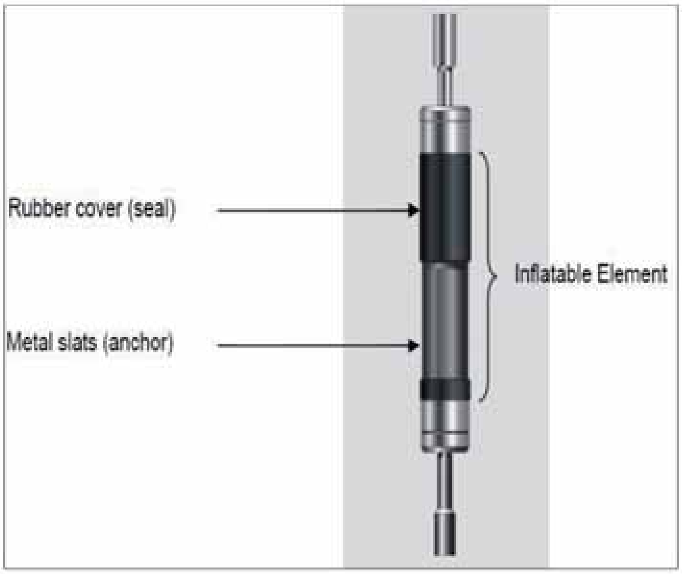


Fig. 2. General construction of an inflatable packer.

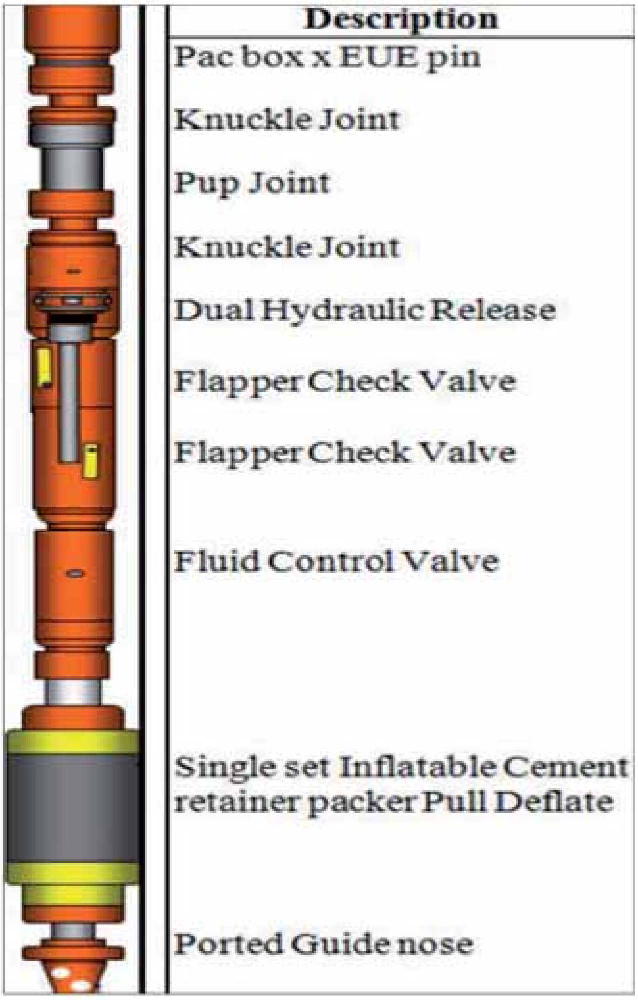


Fig. 3. BHA used for the WSO job.

| | Tubing/Casing Hole Size | Differential and Temperature Ratings by Pressure (psi) Setting Range | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2.00 | 2.44 | 3.00 | 3.55 | 4.00 | 4.56 | 5.00 | 6.05 | 6.36 | 6.97 | 8.09 | 8.76 |
| Element OD (in.) | 1.690 | 5,000 | 5,000 | 4,000 | 3,500 | 3,000 | 1,600 | • | • | • | • | • | • |
| | 1.810 | 5,000 | 5,000 | 4,500 | 3,500 | 3,000 | 2,000 | 1,500 | • | • | • | • | • |
| | 2.125 | • | 6,000 | 6,000 | 5,000 | 4,000 | 3,500 | 2,700 | 2,200 | 1,800 | • | • | • |
| | 2.500 | • | • | 6,000 | 6,000 | 6,000 | 6,000 | 5,000 | 4,000 | 3,400 | 2,800 | • | • |
| | 2.875 | • | • | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 5,500 | 4,600 | 3,800 | • | • |
| | 3.375 | • | • | • | • | 8,000 | 8,000 | 8,000 | 6,500 | 5,500 | 4,500 | 2,350 | 2,000 |

| Temperature Legend | 300°F | 290°F | 280°F | 270°F | 250°F | 230°F |
|---|---|---|---|---|---|---|

Table 1. Differential pressure rating for setting inflatable packers

without undergoing hydrolysis and precipitation.

2. Adequate pumping time: A fluid system capable of controlling cross-linking time (phase change from liquid to gel state) to obtain adequate placement time for a wide temperature range. Figure 1 shows a typical gelation time curve for the OCP system (viscosity and temperature vs. time). The inflection point of the curve corresponds to the gelation time of the system. This transition time is completely controllable and predictable with the cross-linker concentration for a given temperature.

3. Effective water permeability reduction: A system that provides sufficient strength for resisting drawdown pressure inside the wellbore and stopping water flow.

4. Thermal stability: A system capable of keeping its three dimensional gel structure for extended periods of time to provide an effective water shut-off (WSO) at elevated temperatures.

5. High miscibility: The compounds are in solution and are to be diluted with brine. This avoids the lumping problem that occurs with dry polymers.

6. Predictable viscosity profile that can be used to improve diversion over long treatment intervals.

The viscosity of the OCP system is approximately 25 cP at room temperature. Gelation time of the system is controlled by the concentration of the cross-linker. Sufficient strength and thermal stability are obtainable at least up to 350 °F based on laboratory studies. In addition, the OCP system is nonsensitive to formation fluids, lithology and/or heavy metals.

The primary components of the OCP system are:

• Base polymer: Copolymer of acrylamide and t-butyl acrylate (PAtBA), a high activity liquid with enhanced thermal stability.
• Cross-linker: Polyethyleneimine, a high activity liquid that forms strong covalent bonds with the base polymer.
• Mixing brine: Potassium chloride brine, sodium chloride brine or seawater.
• Retarder: A water soluble carbonate retarder is for applications in which the bottom-hole injecting temperature exceeds 250 °F.

The OCP components are easily diluted in the mixing brine. The cross-linking rate is dependent upon temperature, salinity, pH and base polymer and cross-linker concentration.

## Inflatable Packer, IBP, Inflatable Cement Retainer

The inflatable packers, the IBP and the inflatable cement retainer (ICR) are used in the oil industry mostly for isolation of the wellbore in wells with restriction in the tubing. The inflatable tools are able to pass through the restriction and inflate to several times their original uninflated outside diameter (OD)[6]. They are easily deployed using CT or wireline and are robust enough to withstand the difficult treatment conditions for a long period of time. There are two types of inflatable elements, Weave and Slat type, which are used for different application. The Slat type has three main parts,

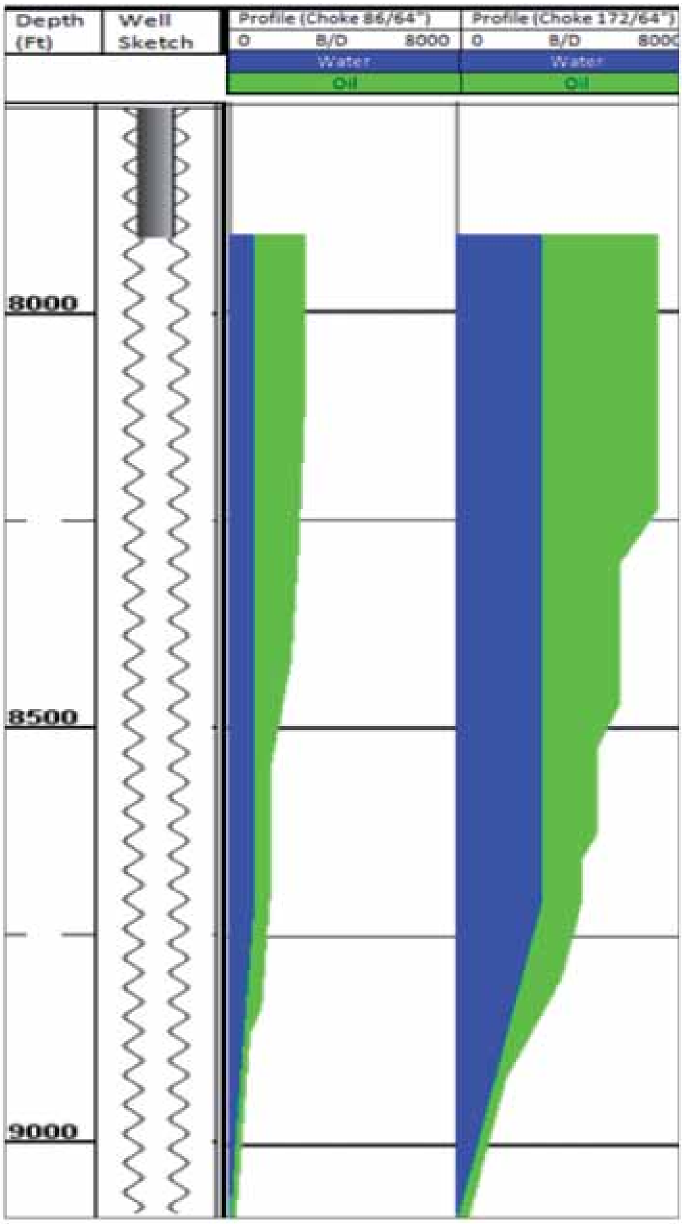


Fig. 4. Well-A production log.

Fig. 2. In all cases, the slats run the full length of the packer elements, whether exposed or not.

- Rubber covers over the slats to provide the seal. The rubber cover is vulcanized in place over the slats and can run the length of the element.
- Exposed metal slat. Slats function like slips, which has high friction forces developed between the metal slats and metal casing. These slats anchor the packer when the tool is exposed to differential pressure in the well.
- Rubber bladder. The whole assembly is inflated by pressurizing a rubber bladder that runs the length of the element, but inside the slats.

The differential pressure to which each of the inflatable packer, IBP and ICR are rated to are based on the temperature and expansion ratio. Table 1 shows the size of the inflatable packer (uninflated OD) and the expanded size with the maximum differential pressure at a given temperature. The bottom-hole assembly (BHA) used for setting the ICR for the WSO job is shown in Fig. 3.

## Job Objective

The objective of this conformance control WSO treatment on horizontal wells in the Ghawar field of Saudi Arabia was to reduce water production from the bottom

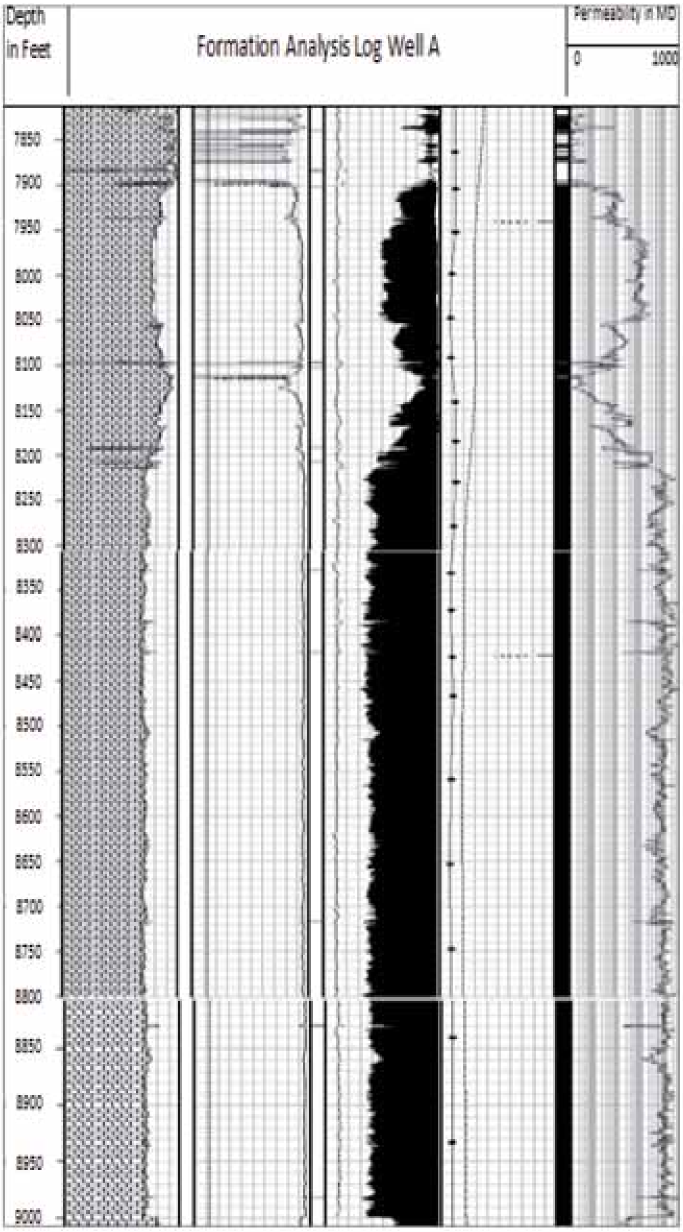

Fig. 5. Well-A formation analysis log.

water producing intervals and increase the oil production from the top interval; which were as per the production log was almost dry.

## Candidate Selection

One of the major challenges for WSO treatments is to significantly reduce water production without damaging the hydrocarbon productivity of the well. Therefore, candidate selection is critical to the success of conformance control. Understanding the reservoir behavior provides the basis for determining the origin of water production and its mechanism of entrance into the well, thereby allowing the conformance team to recommend the best suitable treatment. Much of the success of these treatments is attributed to adequate problem identification[2-5, 7]. Lithological and petrophysical information of the wellbore and the matrix, using a recent production log in conjunction with a formation analysis log, were used in designing the conformance treatment.

Two wells from the Ghawar field of Saudi Arabia were selected for the conformance treatment based on the case history, production history, recent production log and nodal analysis. After a detailed discussion and deliberation with the service provider it was finalized to use mechanical means (inflatable packers, IBPs and

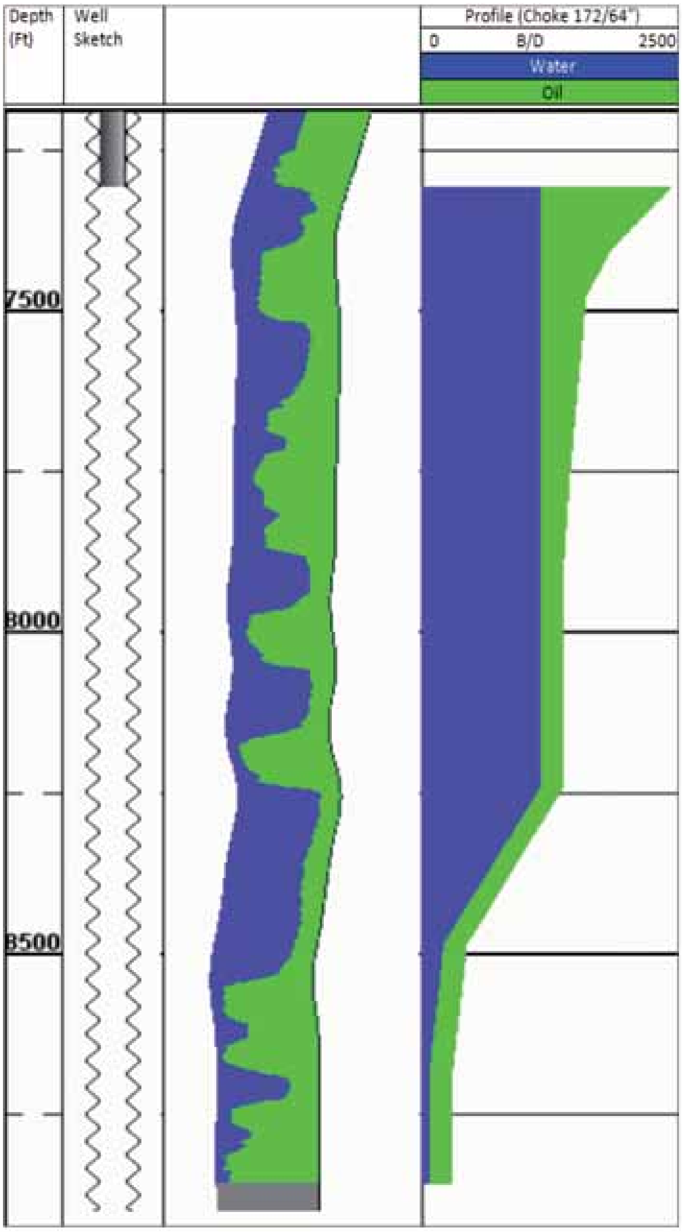


Fig. 6. Well-B production log.

ICRs) to isolate the wellbore and chemical means (OCP) to isolate the matrix.

## Well Description

### Well-A

The well is completed as a 6⅛" single lateral open hole with reservoir contact of 1,182 ft, and was producing 3.6 thousand barrels per day (MBD) of wellbore fluid with 60% water cut. The production log showed all the water is coming from the bottom interval; below 8,700 ft, Fig. 4, with 30% oil production. The average permeability in the wellbore was varying from 700 md to 2,000 md, Fig. 5, as per the formation analysis log and there no natural barrier in the water producing interval.

### Well-B

The well is completed as a 6⅛" single lateral open hole with reservoir contact of 2,160 ft, and was producing 3.8 MBD of wellbore fluid with 55% water cut. The production log showed all this water coming from the bottom interval; below 8,197 ft, Fig. 6, with 34% of the oil production. In addition, the formation analysis log showed that the average permeability in the wellbore was varying from 10 md to 100 md in the upper section and between 100 md to 300 md in the bottom water producing interval, Fig. 7. A low permeable interval of

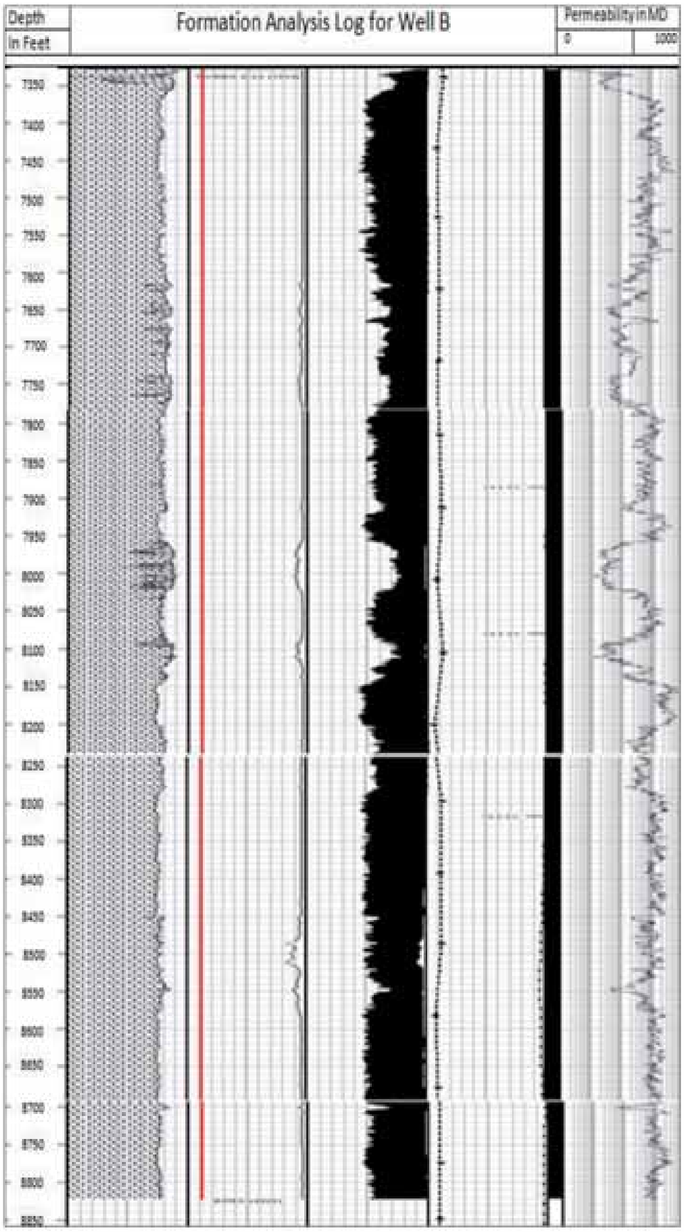


Fig. 7. Well-B formation analysis log.

0 md to 100 md was seen between 7,770 ft to 8,250 ft, which is not contributing to any production.

## Job Planning

### Well-A

Based on the production and formation analysis log it was decided to sacrifice 510 ft of all water producing interval (with 30% oil production) by setting two 3½" ICR (with expansion ratio of 1.75:1), one at 8,650 ft and squeezing 150 bbl of the WSO chemical below the ICR. Based on the simulation it was seen that around 7 ft of artificial barrier will be created in the matrix around the wellbore. On the face of the WSO chemical an additional 5 bbl of rigid setting material will be pumped in the wellbore. The second ICR was planned to be set at 8,580 ft and a cement plug was to be placed between the two ICRs. Figure 8 shows the wellbore simulation of the WSO job planned for Well-A.

### Well-B

Based on the production and formation analysis log it was decided to sacrifice 910 ft of the water producing interval (with 34% oil production) by setting a 2½" IBP (with expansion ratio of 2.5:1) at 8,197 ft and a 2½" ICR at 7,990 ft and squeezing 250 bbl of the WSO chemical between the IBP and ICR. Based on the

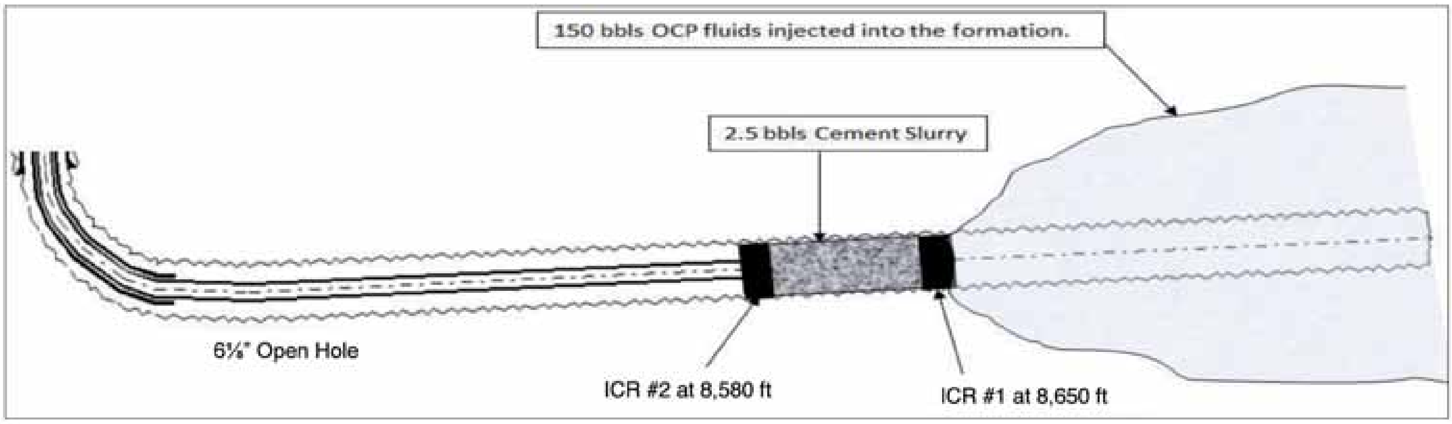


**Fig. 8. Well-A wellbore simulation of the WSO job**

simulation run it was seen that around 7 ft of artificial barrier will be created in the matrix around the wellbore. On the face of the WSO chemical an additional 5 bbl of rigid setting material will be pumped in the wellbore.

## Job Execution

The job was performed using 2" coiled tubing (CT). Since the correct volume was of high importance during this job a ball was pumped through the CT with the lead water having a red color agent added to get the actual volume. In addition, the volume of the tank was ensured by a quality assurance/quality check.

### Well-A

A dummy run with nipple locator and clean out nozzle was executed to drift the well, correlate CT depth, and cleaning out around the planned setting depths of ICRs. An injection test was performed by pumping treated water at a maximum rate of 1.5 barrels per minute (bpm). The CT was then pulled out of hole (POOH) and correlation depths were effectively corrected and flagged. The first ICR was run and set at 8,650 ft and a new injectivity test was performed below the ICR; showing good results. Then 150 bbl of OCP were mixed and pumped below the ICR into the formation matrix followed by 5 bbl of rigid setting material into the well- bore. The ICR's hydraulic disconnect was activated, releasing the ICR packer and starting to POOH, Fig. 9.

The second ICR was run and set at 8,567 ft, Fig. 10, and an injectivity test was performed. After observing good injectivity results between ICRs, 2.5 bbl of cement slurry was placed as an additional barrier for wellbore isolation, Fig. 11. Cement setting time of 8 hours was obtained in lab tests so the well was closed for 24 hours for complete cement and OCP setting. Figure 12 shows the cement compressive strength from the sample taken after mixing cement.

The well was then opened to production but it did not flow. It was suspected that the well was dead due to loading of displacement fluid and contaminants. Therefore, the well was lifted with nitrogen for 8 hours. After this time the well was mostly circulating nitrogen and there was minimal production of hydrocarbons. After stopping $N_2$ lifting, the observed shut-in wellhead pressure was not enough to sustain flow to the gas-oil separation plant. After 6 months of production on/off, the well slowly came up and is presently producing 1.9 MBD with 46% water cut.

### Well-B

A dummy run with nipple locator and clean out nozzle was executed to drift the well, correlate CT depth, and clean out around the planned setting depths of IBP and ICR, respectively. After cleaning the well, an injectivity test was performed by pumping treated water up to 1.5 bpm. The IBP was then run and set at 8,180 ft. For setting confirmation, CT weight of 2,000 pounds was set down on the IBP and it held. The releasing procedure for releasing the IBP from the CT was then applied. When POOH it was noticed that the IBP release mechanism had failed and the IBP was still attached to the BHA. To confirm this, CT was run back in the hole to tag where the IBP was supposed to be, but there was no tag. The decision was then made to push IBP to total depth (TD). Once at TD, the IBP was released from the CT by dropping and chasing the ball to disconnect from the motor head assembly (MHA). A second attempt to set IBP was successfully made after some modifications in the setting and releasing procedure.

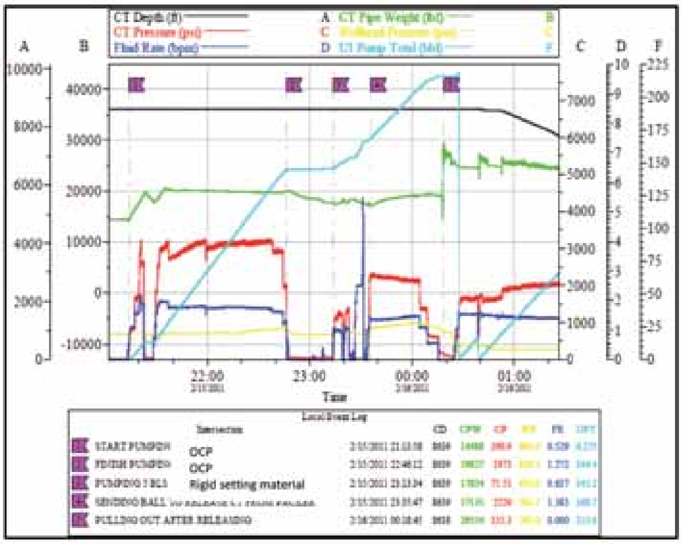


Fig. 9. Well-A pumping WSO chemical and disconnect from ICR.

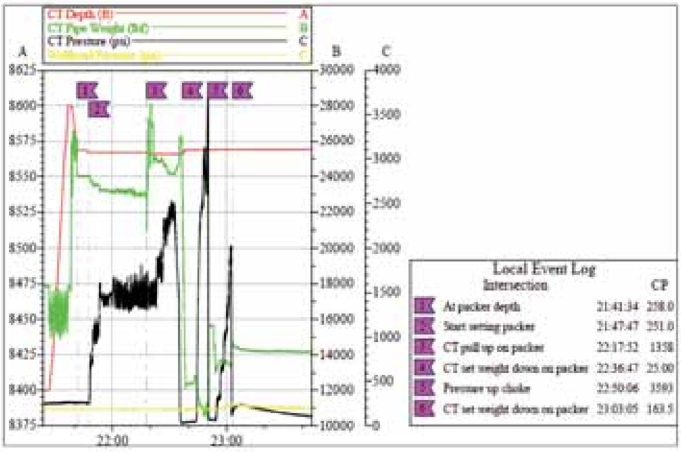


Fig. 10. Well-A: Setting 2nd ICR.

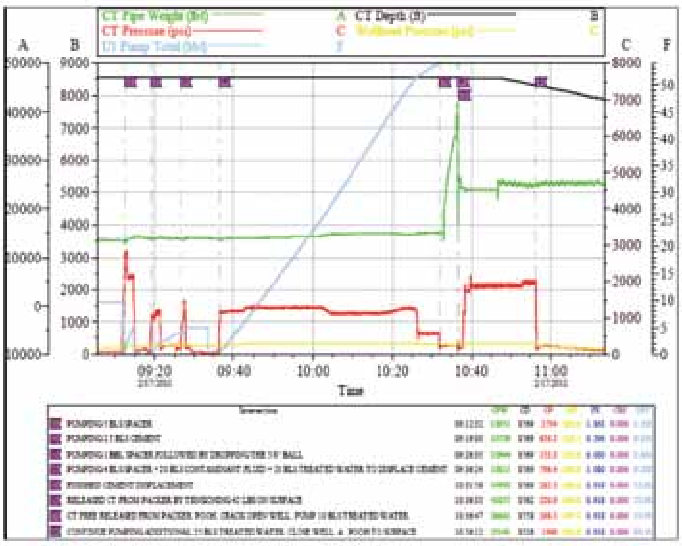


Fig. 11. Well-A: Cement placement and CT release from ICR.

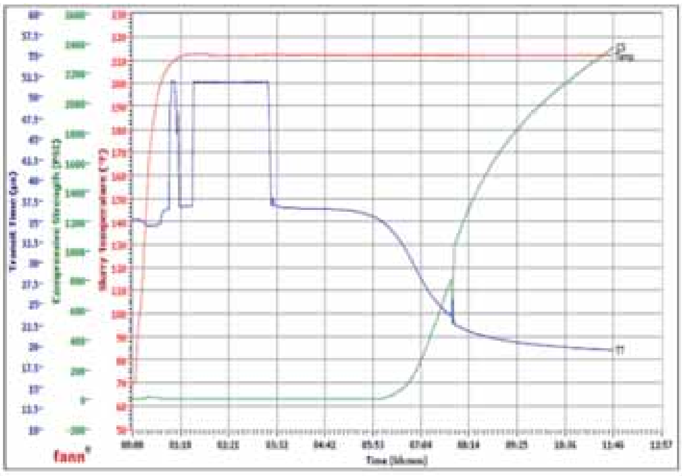


Fig. 12. Well-A: Cement compressive strength

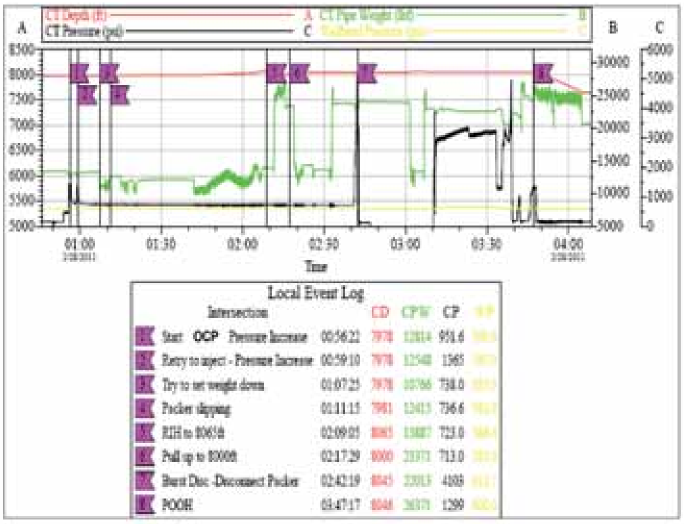


Fig. 13. Well-B: Pumping OCP and disconnecting ICR from BHA.

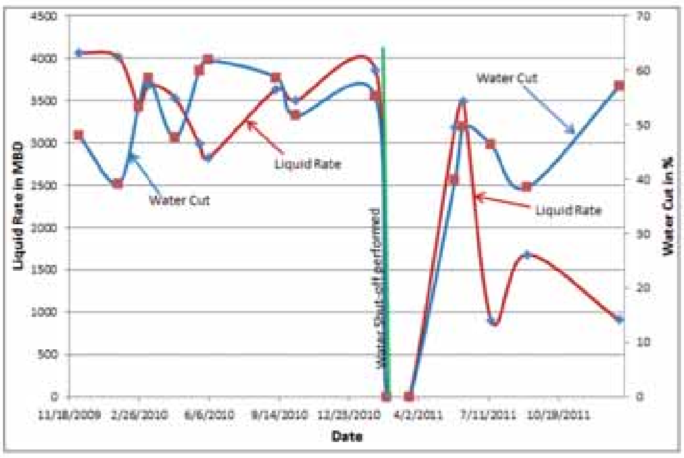


Fig. 14. Well-A: Production performance.

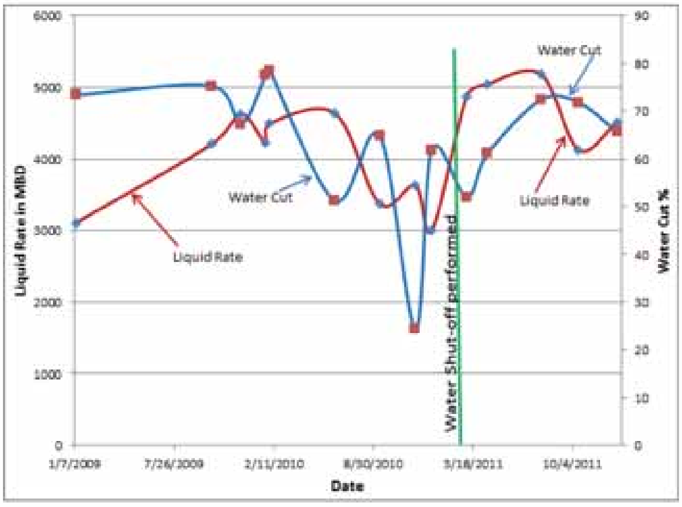


Fig. 15. Well-B: Production performance.

After successfully setting the IBP, the ICR was then run and set at 8,010 ft. An injectivity test between the IBP and ICR packer showed good results. Subsequently, WSO chemical (200 bbl of OCP) was mixed. While pumping, the pressure started to increase rapidly to ~1,500 psi. It was determined that the ICR circulating port was closed. The decision was made to set down weight of 2,000 lb on the ICR, as an attempt to open the circulation port, but the ICR slipped, indicating that it was not holding/set anymore, Fig. 13.

It was then decided to cancel injection of OCP into the formation and move the ICR 40 ft below the initially planned setting depth and disconnect the ICR from the MHA. Later, a cement plug was placed on the top of the ICR to add extra isolation. After waiting for optimum cement setting time the well was then opened to flow and it flowed naturally.

## Post-Job Evaluation

Comparison of the fluid production before and after the job is shown in Fig. 14 for Well-A and Fig. 15 for Well-B.

**Well-A**

The liquid production of the well had dropped substantially; however, the water cut was almost the same as before the WSO job. Detailed analysis established that probably the WSO chemical had partly entered the producing interval and almost complete wellbore isolation had happened. With the passage of time, water production bypassed the OCP system by shallow penetration and made it into the wellbore again. As per Fig. 14 (Well-A), the water cut went back to 60% after a few months, which means the life of the treatment was around 5-6 months.

**Well-B**

Where no OCP was used (only cement) as a barrier, not much happened to the liquid production and water cut. The isolation of the wellbore could not achieve any gain as the water bypassed the matrix and started to produce after opening the well on production.

## Conclusions

1. The conventional WSO by mechanical means and cement placement on the top in horizontal wells has limited success as the water eventually bypasses the shut-in zone and flows in the wellbore through the reservoir matrix.

2. The combination of the WSO chemical with mechanical wellbore isolation is able to block the water production in horizontal wells; however, placement of the chemical in the desired matrix is a challenge. Sometimes the chemical is squeezed in the undesirable interval.

3. Success of the WSO treatment depends on the selection of the candidate well based on proper reservoir understating, well-defined objective, proper design, placement and execution.

4. Using low viscosity WSO fluids is an important factor to evaluate. The lower the viscosity, the better the injection and penetration into the formation matrix. The higher the viscosity of the gel, the greater the problem in pumping, and chances to create new fissures or fractures worsening the problem, thereby leading to reduced treatment effectiveness.

5. It is of paramount importance to accurately determine bottom-hole temperature (BHT) during the planning

stage and way before the job execution since this value drastically affects the OCP and inflatable packer's design and performance.

6. Checking caliper logs to review well stability and shape of the hole is highly important for selecting inflatable packers' setting depth (especially in open hole completion).

7. Information used for diagnostic purposes, such as production history and/or production logging among others, are time sensitive. Since water production is a dynamic condition and the way the formation produces water changes with time (especially in highly horizontal natural fractured reservoirs being depleted), it is highly recommended to apply the WSO solution based on updated diagnostic information. In other words, the time between diagnostic/planning stages and job execution may affect the final treatment performance.

8. In those cases where the desired differential pressure held by the inflatable packer may not be achieved, a dual injection technique is recommended (pumping down by CT and CT/annulus simultaneously). In this regard, it is important to predict, simulate and calculate bottom-hole pressure (BHP) below and above the packer during the injection.

9. Selecting wells with a short WSO treatment interval, in long horizontals and away from the producing zone while using the WSO chemical will give better results.

10. The uncertainty of setting an inflatable packer and fluid injection can be greatly reduced by using fiber optic CT, which provides data such as BHT and BHP (inside and outside the coil). This will help confirm the packer is set and in designing the fluids (WSO chemicals and cement).

11. Setting the packer with a higher inflation ratio (>2.5:1) provides lower differential pressure and in most of the cases is difficult to set.

12. The volume design of the chemical is crucial for the success of the treatment (the more volume injected, the better the results). A balance between the economics and technical approach needs to be determined to get the best cost-effective treatment.

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## Biographies

Hemant K. Sharma is Production Engineer with more than 19 years of experience in the oil and gas industry. His oil and gas experience includes well stimulation, well completion, erection and commissioning and surface facilities. Currently, Hemant is working as a Stimulation and Water Shut-off Engineer in the Southern Area Production Engineering Department (SAPED).

He received his M.Eng. degree from Bhagalpur College of Engineering, Bihar, India in 1990 and an MBA from Indira Gandhi National Open University, Delhi, India in 2005.

Jorge E. Duarte is a Senior Production Engineer working in the Gas Production Engineering Division. His 17 years of experience in the oil and gas industry include production, coiled tubing, cementing and stimulation services, which include matrix and fracturing. Prior to joining Saudi Aramco in 2008, Jorge worked for BJ Services for 11 years and with BP Exploration for 2 years.

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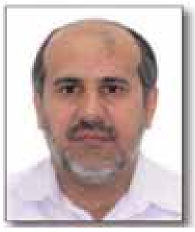
He is a member of the Society of Petroleum Engineers (SPE).



Turki F. Al-Saadoun is a Production Engineering Supervisor. He has been with Saudi Aramco for the past 18 years, working in areas related to oil and gas production engineering and operation. Turki is mainly interested in the field of production engineering and production optimization.

In 1994, he received a B.S. degree in Petroleum Engineering from King Saud University (KSU), Riyadh, Saudi Arabia.

Turki is a member of the Society of Petroleum Engineers (SPE) and he was previously selected as the Southern Area Oil Operation area liaison for 2 years in 2008-2009 and 2009-2010. Also, Turki is a member in Saudi Council of Engineers.

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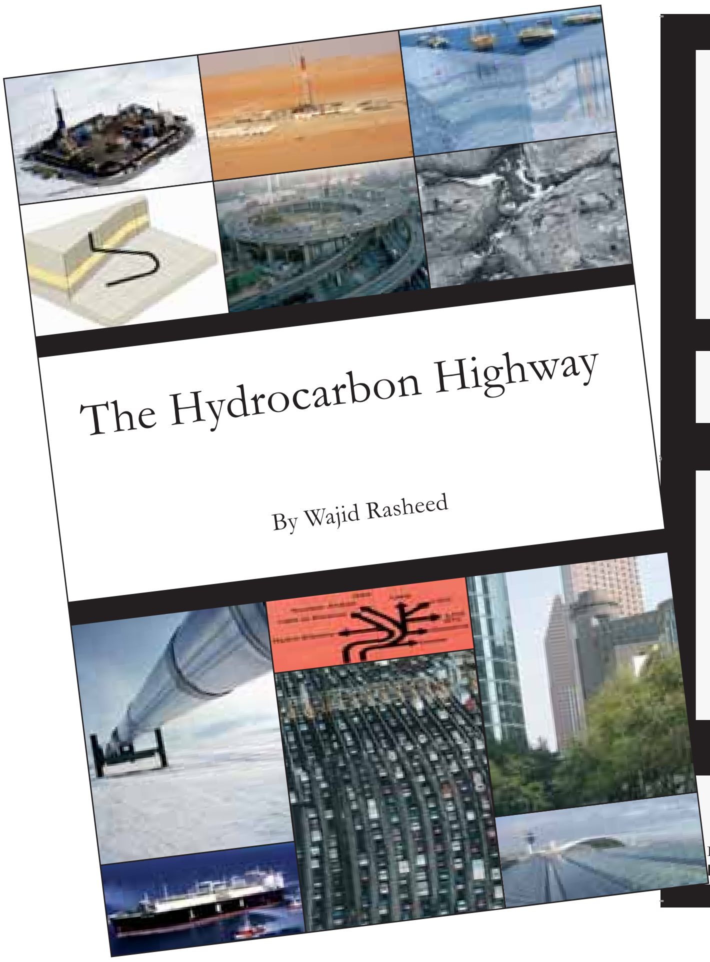
In 1990, he received his B.S. degree in Civil Engineering from the Instituto Universitario Politécnico de las Fuerzas Armadas Nacionales (IUPFAN) and in Metallurgical Engineering from the Universidad Central de Venezuela (UCV), Caracas, Venezuela.

Jose is a member of the Society of Petroleum Engineers (SPE) and has authored several technical papers on field technology applications, fluids and stimulation results.

# Paper Barrels – Oil and Gas Markets





*'Please Lord, give us one more boom. We promise we won't screw it up this time'.*

Trading of paper barrels, such as oil futures and oil derivatives, characterise today's oil and gas markets and add further volatility to oil prices. The trillions of dollars that are found in hedge funds operated by commodity traders and speculators often follow a herd mentality. This magnifies the effects of geopolitical unrest or natural disasters by creating panic buying or selling situations. Hedge funds and speculators need prices to oscillate to make profit—buy low, sell high and buy low[1].

## Nature's Best

You don't have to trade commodities to know the simple rule: the best quality fetches the highest prices. Just go down to a coffee shop; the best beans command a

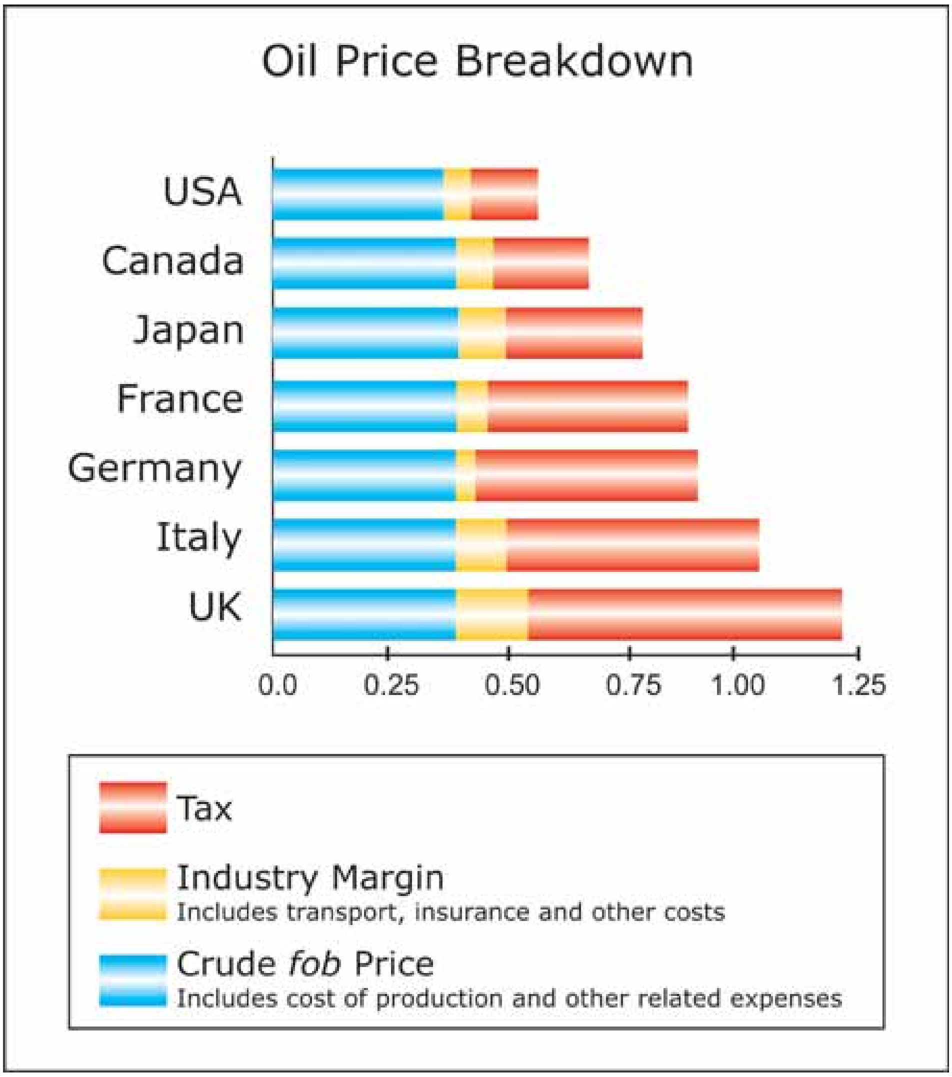



**Figure 1 - Oil Price Breakdown (OPEC)**

premium. Oil is no exception to the quality rule, yet the prevailing stereotype is that a group of oil barons in Dallas or oil sheiks in Dubai control prices behind closed doors. Thankfully, the reality is somewhat more transparent with petroleum prices being determined by market forces, quality and trading.

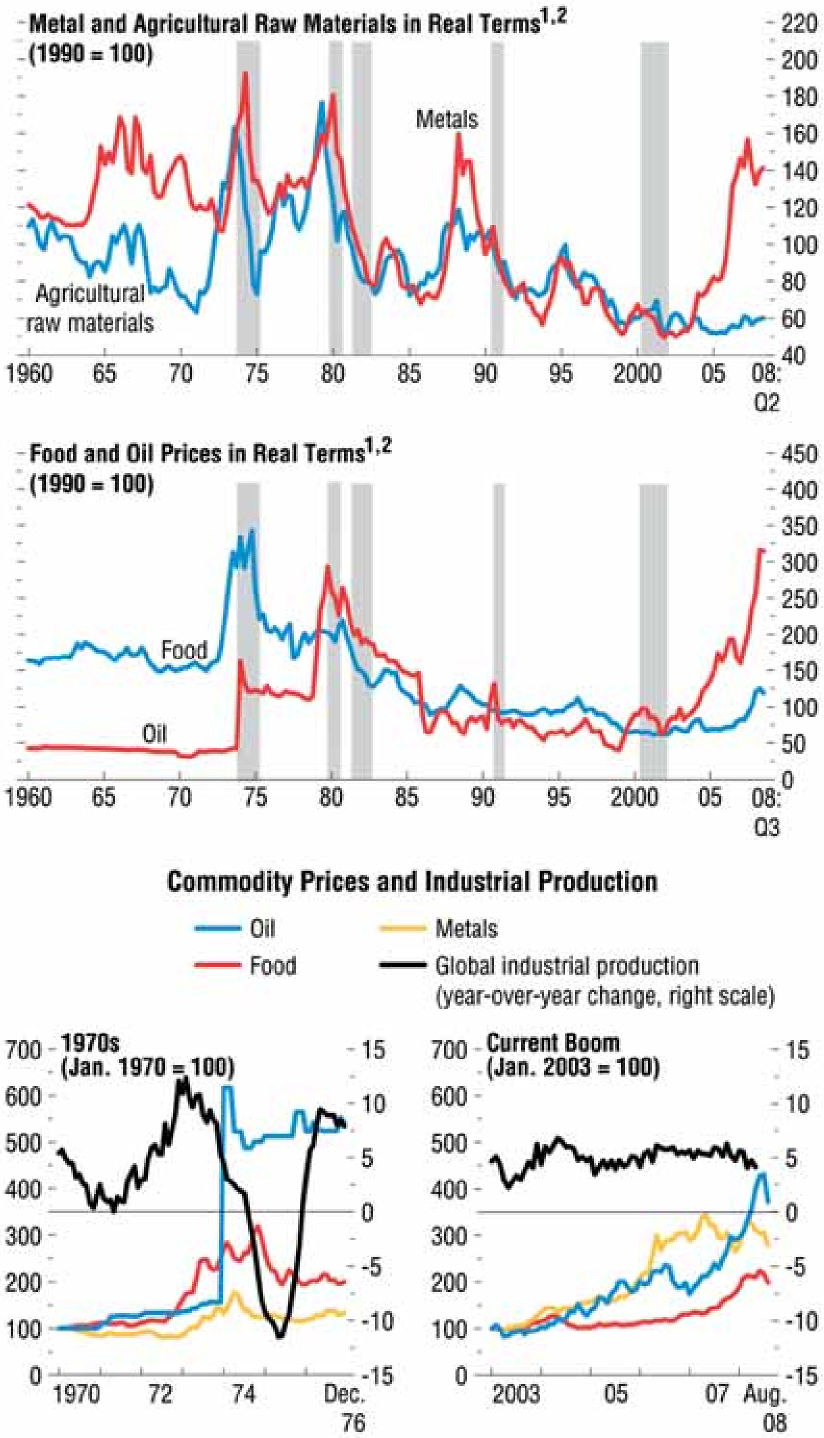
## Pricing Is Complex

The pricing of petroleum is highly complex. Making comparisons between producers regarding what is a fair price for oil and gas is a tough call. This is because it would involve selecting countries that match each other's profiles in terms of oil and gas exports and imports. Almost all petroleum exporters import petroleum either for derivative needs or to maintain refining blends for national refineries. Even then, the comparison would be invalid due to differing circumstances such as:

- Fiscal arrangements
- Production agreements
- Royalties
- Tax breaks
- Seasonal adjustments and their affect on West Texas Intermediate (WTI) crude (which does not necessarily apply to Brent crude)
- Discounts and sunk costs for a certain type of refinery configuration for a certain basket of crudes
- Per barrel finding costs, and
- The sweetness and density of the crudes being imported and exported[2].

The following example is instructive. Consider that sweet WTI crude trades at US $X on a given day. WTI Sour would trade at a lower rate between US $3.75 to $5.00; therefore, WTI Sour would trade at approx.

The current commodity price boom shares many common features with the most recent major commodity price boom, during the early 1970s, including sharp increases in oil and food prices and an environment of strong global growth.




Source: IMF staff calculations.
[1]Deflated by U.S. consumer price index (CPI).
[2]Shading denotes periods of global recession (identified by a monthly index of global industrial production).

**Figure 2 - IMF Commodity Prices (Source IMF). Note the commodity boom clearly burst in late 2008**

Figure 3 - When You Can See the Iceberg It's Too Late to Change Course

$X-$3.75 to $X-$5.00. A sliding scale operates that knocks down the price according to sourness. A 50° API sour would trade at approx US $68.25 per barrel although the marker WTI would trade parallel at US $90 – a price differential of nearly US $12. Additionally, crude that is below 25° API, would fetch lower prices. Roughly speaking, 20 cents is deducted for each API degree below the benchmark. For crude below 20° API, 70 cents would be deducted for each API degree[3]. This gap is likely to increase in the future due to the shortage of sour and heavy refineries.

> "Hedging or speculative investments are unregulated financial instruments where traders look for a 'margin' between market value and real value."

Petroleum pricing is further complicated due to variations in the type of oil company, its internal marketing channels, the age of refineries involved as well as their configuration, efficiency, ownership, economies of scale and sunk costs[4].

## Oil and Gas

The split between oil and gas production is always important because oil and gas are priced according to their nature and utility. Gas pricing is different to crude oil pricing mainly due to the long-term contracts which can be as long as 20 years, a situation which is unthinkable in oil futures. Even the most progressive and forward thinking oil companies or oil traders will not likely contract beyond a few years. This leads us to the second fact: differences exist in oil contracts between oil companies and traders and oil contracts 'off-the-trading-floor'. The latter are not hushed up for secrecy purposes, but for more mundane reasons—getting the right blend for refining[5].

## Trading

Everyday billions of dollars worth of petroleum contracts are traded at exchanges around the world. The most famous are those of the New York Mercantile Exchange (NYMEX), Chicago Mercantile Exchange (CME) and the Intercontinental Exchange (ICE) London. These exchanges act as trading venues by bringing buyers and sellers together. These exchanges do not control price, nor can they intervene to stimulate demand or supply. What they offer is the certainty and anonymity of a regulated trading place. Today's corporate governance and anti-trust laws make price fixing and monopolies a historic relic. Regulated contracts are generally either here-and-now (spot) contracts or set at a pre-determined date (futures). These contracts allow buyers and sellers to hedge against future risk, oil price increases or reductions. Hedging or speculative investments are unregulated financial instruments where traders look for a 'margin' between market value and real value. Their profits are made when the values differ[6,7,8].

## Auto-Pilot

Bright blazers, frenzied finger signs, shouting and paper strips littering the floor – the unmistakable scene of open pit trading. In 2005, London's open-pit petroleum exchange became completely e-based. Buyers and sellers instruct brokers who set e-tag alarms at given bid-to-buy or offer-to-sell levels. This has removed much of the human element in petroleum trading making it almost automatic execution. Although this removes an element of panic, prices are still influenced by volume transactions or the 'herd' mentality. The NYMEX still maintains open pit trading, but it is only a matter of time before this too becomes automated.

## Control or Influence?

No single body, organisation or even nation state is

> If a trend for oil prices has been established, and is achieved by all the world's producers and consumers, this trend can only be undone by the same combination.

capable of controlling oil prices without inflicting major harm on itself. If a trend for oil prices has been established, and is achieved by all the world's producers and consumers, this trend can only be undone by the same combination. Of course, certain institutions may be able to influence the trend, but the underlying trend is far too diverse and powerful to be broken. Not even the world's financial muscle can control oil prices. Banks and billionaires can clearly influence prices by buying and hoarding physical oil stocks. They can suddenly offload oil at high prices, and buy it back at a lower price; however, the daily volumes involved just to make a difference would be huge (one million barrels a day [MMbbl/d] would cost many millions of dollars). Considering, the severity of the current banking crisis, it is hardly likely either banks or billionaires will want to hold substantial volumes of oil.

To see the trends clearly, consider that by the end of 2008 the Organisation of the Petroleum Exporting Countries (OPEC) had promised a production cut of two MMbbl/d—the largest cut in its history. Yet, this had minimal impact on the downward trend. To contrast, in early 2005 in certain European markets, some finance houses profited from rising oil prices by chartering oil tankers and storage facilities to hoard oil; however, they were profiting from an upward trend not creating one and were able to access capital easily.

Even the powerhouse of OPEC, which supplies roughly the equivalent of 40% of the world's crude oil, is unable to determine prices. Of course, OPEC and its constituent state companies influence the market by increasing or decreasing production. They cannot, however, reverse or start a trend that is already underway[9,10,11].

But what if suppliers increased production in an upward-market? In theory, this should send prices spiralling downwards due to excess supply. In reality, however, the supply-demand equation is so tightly reckoned that insufficient spare capacity exists that could actually pump more oil or gas, let alone refine, market and distribute it. What if the suppliers reduced production in an upward-market? Of course, this would increase prices. In the normal course of business, however, this is not likely as producers want to make the most of high prices.

If oil prices become too high, this will induce inflation and restrict global growth, reducing consumption and bringing prices downwards. The oil producers seek stability; they are highly dependent on oil and gas revenues. If supply was shut off completely, that would send economic shockwaves worldwide as in the 1970s. While it may be possible, this is not likely to happen in the normal course of business[12].

On the demand side, as long as world economies continued to grow (even at very low rates, i.e. 0.25%

> As demand is so heavily dependent on economic health, any change in consumption will affect producer decisions regarding production output, exploration spending, etc.

per annum), oil demand does not falter and oil prices maintain their high levels. However, as soon it was clear that world economies were going to falter in late 2008, demand dropped so fast that by early 2009 the oil price was US $40 per barrel. This was a drop of more than US $ 100 within less than six months.

### Consumers and Producers Dance Together

Consumers and producers are locked in a complex and inescapable equation that continually attempts to balance trillions of supply and demand transactions. To comprehend this, we need to look beyond politics and realise that producers and consumers are mutually dependent. Although certain countries hold the world's long term oil and gas reserves, those reserves are only ever of real value if they are marketed.

Giant consumers such as the US, Europe and China need to meet demand for heating, cooling, lighting and mobility. Other consumers such as Brazil and India are growing demand. As demand is so heavily dependent on economic health, any change in consumption will affect producer decisions regarding production output, exploration spending, etc. That much seems clear.

What is not clear is the time delay between a growth or fall in consumption and the reactions of producers. Not only is this delay so protracted that it goes unnoticed, it is also deadly. Why are we consistently unable to spot the dangers of 'boom and bust' cycles? Since biblical times, and the seven years of feast followed by seven years of famine, why is it that we always get hit?

Just like the Titanic and the iceberg, it seems as if the cycle has suddenly come from nowhere. Bang. By the time we get hit, it is too late to change course. But is our fate the same as that of the Titanic[13]?

Large economic swings leading to excess production or consumption are not in the interests of producers and consumers. They can lead to recession and even depression; therefore, it is in the interests of both groups to maintain stability. Ultimately, however, the market balances the uncertainties of economic growth and oil price. But how does affect the oil and gas industry?

### Cycles

Clearly, the major determinant of oil company profits and share prices is the oil price. As such, it is a crucial

> Despite experience reminding us that cycles do not last forever, the tap is opened or closed, and the flow that follows always compounds the boom or bust.

factor in pacing industry activity. It dictates budgets and investment throughout the industry from E & P spending, rig activity, wells, facilities, refineries and pipelines. It is relatively easy to see where the industry is in a given cycle by looking at oil prices. If they are low, so are share prices, capital expenditures, rig levels, drilling and activity in general. When oil prices rise, the opposite applies[14].

From an investor's perspective, ExxonMobil, BP, Royal Dutch Shell and ChevronTexaco all enjoyed an increase in absolute values in line with high oil prices and record corporate profits. Independents and service-company stocks had a similar story. Anadarko, Burlington, Baker Hughes, Halliburton, Schlumberger, Smith and Weatherford experienced relatively large gains. Both majors and services, however, had tremendous fluctuations in unison with cycle movements thus wiping off billions in market share values as oil prices dropped in late 2008.

## Down Cycle

But how does that affect the industry? It's no secret that markets are ruthless. Since the 1970s, the boom and bust cycles have seen oil prices and drilling activity crash three times – twice due to the wider recession in the world economy and once due to the Arab-Israeli war. Two clear patterns emerge from these cycles. First, just like the market traders, the upstream industry is dominated by a herd mentality too. Despite bust markets offering less expensive stocks, rigs and labour, drilling levels never rise; they fall. Second, the industry is regulated as if it were a tap. Despite experience reminding us that cycles do not last forever, the tap is opened or closed, and the flow that follows always compounds the boom or bust [15].

To illustrate this, since the US $10 oil price in 1998, basket crude prices doubled to above US $20/bbl by 2000, doubled again to US $40 by 2004 and nearly doubled again reaching US $78.40 in 2006. By July 2008, they had reached a peak of US $147. Although oil prices have more than doubled three times since 1998, exploration spending has only increased marginally in comparison.

Despite lower E & P budgets relative to the increase in oil price, most rig contractors and oilfield service companies have all recorded record profits and high utilisation levels. The reason is that demand for equipment and services has been very high and technological forces have also been at play.

> "As the desire for modernity spreads, lifestyles that were once confined to wealthy classes in wealthy countries are now found up and down social classes and across the globe ..."

We have seen that fewer wells are being drilled, but they are far more effective at drainage and production is increased. Better technology such as sub-salt imaging is helping to discover fields such as Tupi in Brazil, while directional drilling techniques can access and enable multiple reservoir completions. Yet, once again faced with uncertain economic conditions, the industry is faced with cost-cutting[16,17].

### Big Crew Change

Arguably the industry's most valuable resource, upstream labour, suffers the most when the tap closes. The 'big crew change' refers to an ageing population that is creating a labour deficit across all skills and capacities, but is largest in technical areas. Many people who are laid off exit the industry and potential new entrants remain wary. Today, nearly half of all oil and gas industry workers are over the age of 50. Only 15 percent are in the age range of 20s to mid-30s. University enrolment in petroleum engineering is down from 11,000 students in 1993 to 1700 today. The number of universities with petroleum engineering degrees has fallen from 34 to 17. Companies searching for their future leaders are fast realising they are going to have to do things differently; there are lots of intellectual gaps. We're seeing more outsourcing, greater dependence on suppliers to solve problems and higher demand for consultants[18].

### Oil – Profits or Profiteering?

Rocketing oil and gas prices and record corporate profits are almost always accompanied by the pockets of consumer's hurting. This leads to greater scrutiny of oil and gas companies, yet what are the issues surrounding petroleum prices and corporate profits[19]?

Nobody wants oil or gas. What people want is the progressive lifestyle that oil and gas provides. It's all about comfort, freedom and consumption. We want the 'climate-comfort' that comes from heating or cooling our homes, our workplaces and malls. We want the freedom that comes from driving our cars or from flying anywhere. We want derived goods such as aspirin, plastics and cosmetics. No other commodity touches us so completely or underpins modernity as petroleum. Undeniably, we are 'petroleum people'.

As the desire for modernity spreads, lifestyles that were once confined to wealthy classes in wealthy countries are now found up and down social classes and across the globe—not just China, India, Russia and Brazil but the wealthy states of the Middle East. Together, this relentless social mobility has contributed to oil becoming in many

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ways the world's most desired commodity [20].

### Petroleum Generation

Emotions run high because everyone wants a better lifestyle or at least a more comfortable one, and oil and gas can make this happen. It's that simple. If we strip away our needs from our wants, however, it becomes clear that we do not need everything we want. Linked to this, we can also use energy more efficiently.

Of course, no one is suggesting that air-conditioning in the tropics (gas power generation) is unnecessary or that heating (gas fired) in cold countries is a luxury. What is important here is that we don't need to drive everywhere, but we want to. It just seems easier to get to the shops, to work and to the gym. Our language is telling; often our first car is a little 'runabout' for local journeys[21].

As petroleum people, we drive everywhere – no matter how short the distance – and we fly. Where past generations would have seen flying as a once in a lifetime experience, we think nothing of flying to visit people, go shopping or even to get a 'winter-tan'.

### Lifestyle Price

It's fine that lifestyles come with a price. The logical question is at what price and who should pay. The logical tendency is that those that pollute should pay. What this means is that those people that live in Northern climates must get used to paying higher prices, especially during peak demand periods such as winter. Those that inhabit temperate climates will pay more for their energy, especially in summer. Everyone can expect higher gasoline prices. As students of economics will be quick to point out, this is demand and supply theory at work. In this context, what is a fair price for the lifestyle? All commodities can fluctuate wildly according to seasonal production changes and non-scheduled events such as droughts or flooding. See the peaks and troughs of orange juice or coffee futures; where crops are plentiful, prices fall. The reverse is also true. Without exception, oil and gas are commodities which are subject to price fluctuation[22].

### Cheap Oil

Getting it on the 'cheap' is a reality for only a handful of countries that 'enjoy' heavily subsidised oil such as Venezuela and several Arabian and central Asian states. Of course, the artificially low prices that these countries enjoy mean that part of oil revenues are transferred directly to consumers' pockets. Some commentators have decried this as distorting demand by allowing artificially low prices which lead to greater demand. That may be true, but the decision to remove taxes from gasoline sales in given countries is a sovereign decision and right. In some ways, it is an easy method of spreading the profit.

It is clear that the oil price is determined globally by many buyers and sellers engaging in trillions of transactions: however, the time-delay before we can measure the difference is so long that it often catches us by surprise (who remembers the last bust cycle when it was a decade ago?) This is best characterised by the Texas car sticker—'Please Lord, give us one more boom. We promise we won't screw it up this time'.

In the long term, as long as economies and populations grow, demand will inevitably increase. On the supply side, three major world producers—Venezuela, Iraq and Nigeria—have had reduced production for four successive years. Add to this the spate of hurricanes and other non-scheduled events to use an analyst's term, it's hardly a surprise that oil and gas peaked recently.

But what is the trend for the future? Will renewables change the equation? What of global warming and climate change? The next chapter looks at these two points specifically. By understanding where renewables fit into the oil and gas equation, we will be better placed to understand which are the true exits from the Hydrocarbon Highway[23].

## References

1. The cycle can be self-fulfilling and examples are the 'contango' situation in oil futures where spot prices are lower than long term futures or backwardation where spot prices are higher than futures.

2. The difference between imports and exports can make a huge difference to profits.

3. This is a guideline pricing differential for illustration only.

4. Planned maintenance is a growing problem as the refinery stock ages.

5. With increased volumes of heavy and sour oil blending and purchasing is already becoming a complex trading task.

6. The New York Mercantile Exchange handles billions of dollars worth of energy products, metals, and other commodities being bought and sold on the trading floor and the overnight electronic trading computer systems. The prices quoted for transactions on the exchange are the basis for prices that people pay for various commodities throughout the world.

7. The Chicago Mercantile Exchange was formed in 1919. Initially, its members traded futures contracts on agricultural commodities via open outcry. This system of trading—which is still in use today —essentially involves hundreds of auctions going on at the same time albeit with today's electronic option available too.

8. ICE conducts its energy futures markets through ICE Futures Europe, its U.K. regulated London-based subsidiary, which offers the world's leading oil benchmarks and trades nearly half of the world's global crude futures in its markets.

9. The oil and gas markets are simply too large for any single group to control prices.

10. There would be too many variables between OPEC and non-OPEC producers let alone considering consumer countries.

11. TTNRG Nature's Best.

12. This would hurt producers equally with the loss in revenues.

13. The Titanic sank for good; oil and gas markets go up and down

14. Harts E & P Sept 2002 Drilling Column. 'Manage your tapped resources'. Discussion on industry cycles.

15. Idem.

16. Despite economic uncertainty certain deepwater projects are still going ahead.

17. See Yergins Prize 'Sweating'.

18. The Big Crew Change.

19. See 2005 US Senate Inquiries into Oil Prices.

20. Global economic growth has slowed down during the current recession but it will not disappear.

21. The comfort lifestyle.

22. See IMF commodity price charts.

23. This is the basis for substituting oil.