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2011 – Issue 19

Saudi Arabia oil & gas

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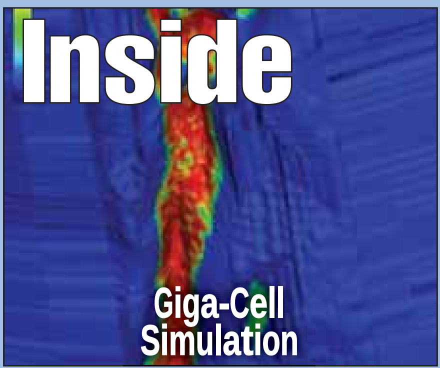

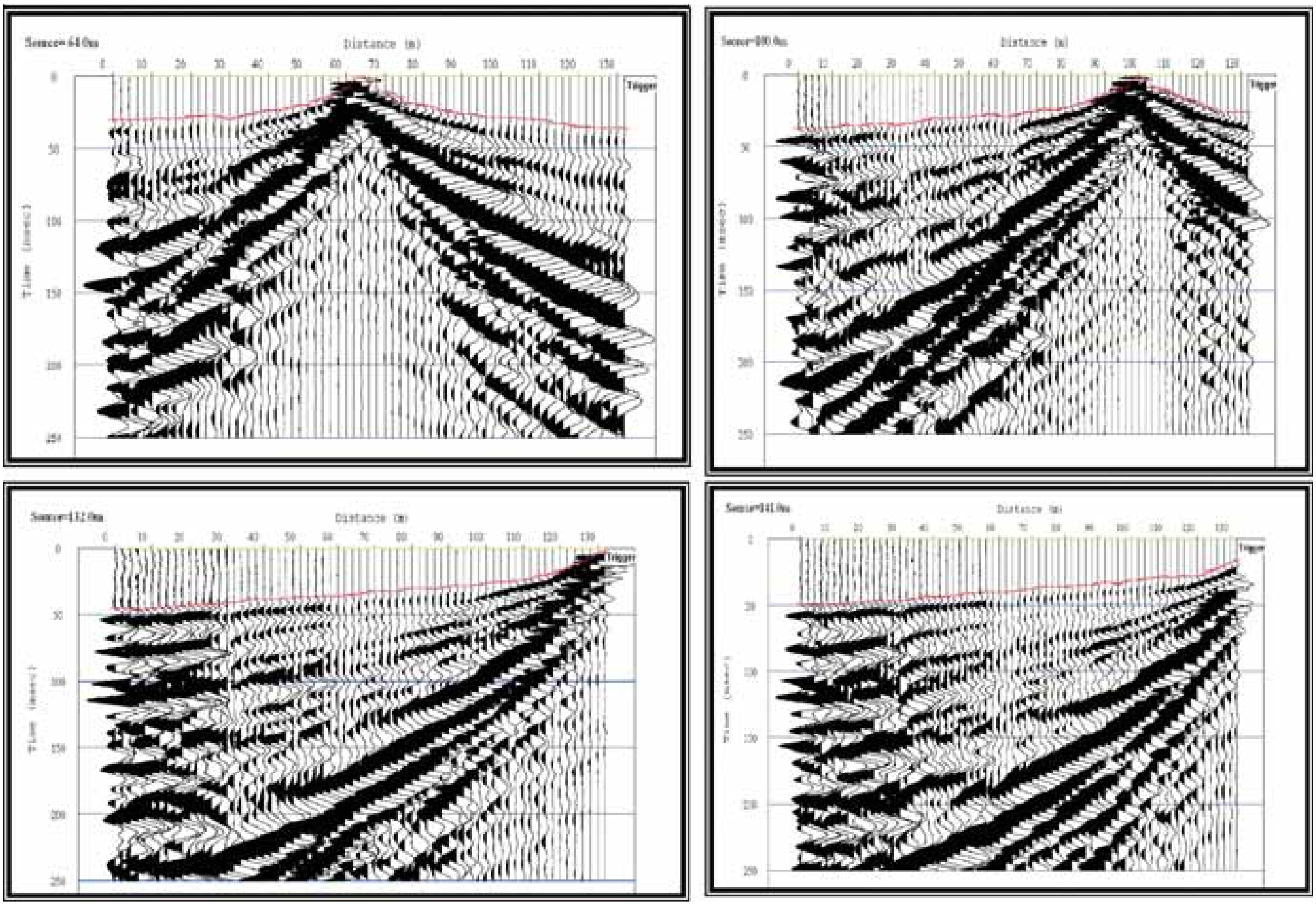

Examples of shot records for conventional refraction analysis.


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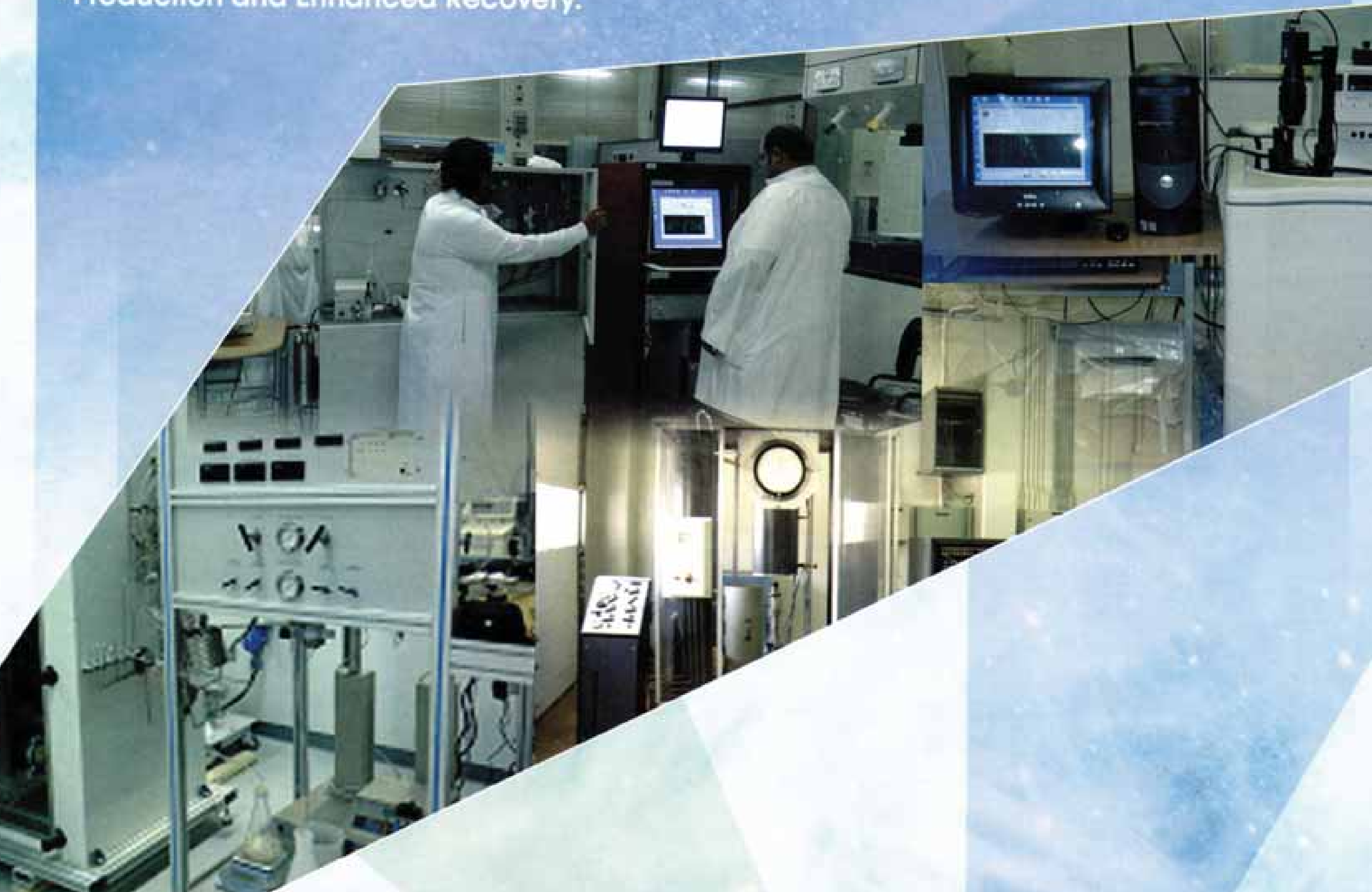
Hydrocarbon resources (crude oil and gas) are the main source of world energy, and as the international demand increases, the technical challenges increase to meet that demand. Hydrocarbon production optimization at minimum cost and the need to serve the national petroleum industry has been the driving 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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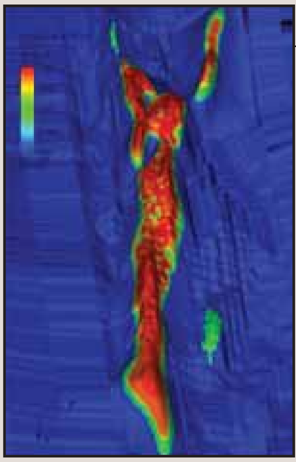

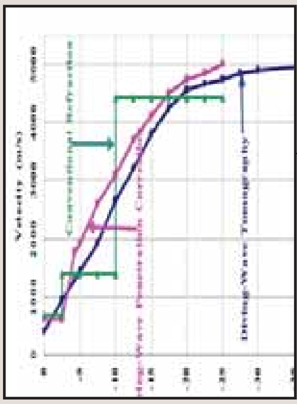

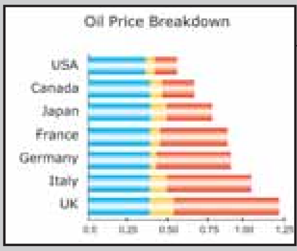

Tackling Upstream Challenges:
Fueling the World

Safely

Reliably

and Cost-Effectively

2011
ATS&E
ANNUAL TECHNICAL SYMPOSIUM & EXHIBITION

15-18
May 2011

Khobar, Saudi Arabia
Seef Center

SPE International
Saudi Arabia Section

2011 SPE | DGS Annual Technical Symposium & Exhibition

DHAHRAN GEOSCIENCE SOCIETY

Dear Colleagues,

I would like to invite you to the 2011 Annual Technical Symposium and Exhibition (2011 ATS&E), which will be held in AlKhobar, Saudi Arabia, May 15-18. The event is organized by the Saudi Arabian Section of the Society of Petroleum Engineers (SPE SAS) and the Dhahran Geosciences Society (DGS).

This annual event is the largest gathering for engineers and geoscientists in the region. It attracted more than 2,500 participants last year. The event has evolved to become a major gathering for knowledge transfer, experience exchange and networking in the Gulf region.

The annual growth journey of the ATS&E continues strongly in 2011. The Symposium received a lot of international attention where the Program Committee received abstracts from more than 30 countries. With a total number of 412 abstracts received, the 2011 ATS&E broke every record throughout its history. With this powerful momentum, we look forward to an outstanding Symposium in AlKhobar.

This year's theme, 'Tackling Upstream Challenges: Fueling the World Safely, Reliably and Cost-Effectively', calls for new technologies in all operations related to the exploration and production of oil and gas. In the Middle East, by the year 2020, the Energy International Association (EIA) has forecast a 60 per cent increase in energy consumption compared to the history of consumption in the year 2005. In addition, new fossil fuel discoveries and production are more challenging. Thus, the development of new technologies becomes the essential means to meet ever-increasing energy demands.

The 2011 ATS&E program and its pre-event activities are offered at no cost. There will be four pre-event courses and a workshop, 20 technical sessions, a panel discussion and a poster session. In addition, there will be three awards for the 'Best Papers' and a 'Best Poster' Award. The program will include an open day for high school students titled 'Your Future Career' to introduce various engineering and sciences disciplines to them. This aims to help them select their future college major. This is part of the SPE SAS Young Professionals activities associated with the ATS&E.

I would like to invite you to actively participate in the Symposium, either by attending its technical program, sponsoring an event or participating in its exhibition. Please visit our Symposium website www.atse2011.org for more information. I would also like to thank Saudi Arabia Oil and Gas as the official journal.

Thank you, and I hope to see you in AlKhobar next May!

Please do not hesitate to contact me if you have any questions.

Dr. Ghaithan A. Al-Muntasheri
Chairman, 2011 SPE/DGS Annual Technical Symposium & Exhibition
email: Ghaithan.muntasheri@aramco.com
www.atse2011.org

The First Saudi Finance Professionals Forum

By Aref M. Younis.

DAMMAM, April 06, 2011 – The business of finance has changed dramatically, forcing finance professionals to take on ever-expanding roles, participants learned recently at the First Saudi Finance Professionals Forum.

Abdullatif A. Al-Othman, left, addresses attendees at the First Saudi Finance Professionals Forum.

The forum, held on March 2 at the Dammam Office Building, was organized jointly by Saudi Aramco Finance and the Saudi Organization for Certified Public Accountants (SOCPA) and brought together more than 350 finance managers and professionals.

Abdullatif A. Al-Othman, senior vice president of Finance, after welcoming the participants on behalf of Saudi Aramco, focused on the "Evolving Role of Finance and the Need for Top Talent."

In today's economy, he said, financial professionals from around the world are being called upon to serve technical roles as well as to contribute to strategic planning, innovation and management.

"More recently," he said, "finance organizations have been challenged to not only provide data but to provide analysis and insight to enhance business decisions, measure corporate performance and engage in strategy formulation. What we've witnessed is a change in the expectations placed on us as finance professionals."

Saudi Aramco's financial professionals will join others in the Kingdom to partner with universities in their educational programs. "Together," he said, "we can provide insight to ensure that curricula include courses and experiences that will promote and enhance business and finance knowledge, as well as the development of basic soft skills and competencies."

The Finance organization conducts frequent orientation programs for new employees, including new hires from the Kingdom or abroad, and employees transferring to finance from other business lines. Each orientation includes team-building exercises and development of initiatives to improve the work of the company.

So a team-building exercise devoted to corporate social responsibility was the genesis for the forum, Al-Othman said. "In other words, we owe the existence of this forum to a group which, by its very nature, took a fresh look at things and proposed an initiative from the grassroots."

Controller Mohammad A. Al-Ali said the Finance organization was happy to host the forum in an effort to help establish a platform whereby representatives from SOCPA, the financial services sector, industry and government can meet annually to review and discuss current and emerging issues facing their organizations.

"The one-day forum," Al-Ali said, "will promote a sense of common purpose among finance professionals and help them focus on the significant roles played by financiers in helping entities make better decisions."

9th Meeting of the Saudi Society for Geosciences
26 – 28 April, 2011
on the Campus of
King Saud University - Riyadh.

First Circular: February 2010 - Second Circular: October 2010

CALL FOR ABSTRACTS

The Saudi Society for Geosciences invites all concerned geoscientists and experts to participate in the activities of its 9th meeting which will be held in the campus of King Saud University, Riyadh.

The main objective of this meeting is to advance and enhance the geoscientific knowledge in the geology of the Arabian nation and its relation to the sustainable development. This goal will be achieved and implemented through exchanging ideas and experiences among participants from Arab countries.

The meeting will include oral presentations, panel discussion, workshops and exhibition. External and Internal Keynote speakers will be invited. Details of the meeting will be posted in the second circular.

MAIN THEMES

1- Geology of the Arabian Nation
2- Explorational Development of Natural Gas and Petroleum
3- Sustainability and Development of Water Resources
4- Exploration & Exploitation of Minerals
5- Environmental Geology & Engineering
6- Remote Sensing & GIS Applications
7- Applied Geophysics
8- Geotechnical Engineering
9- Seismology & Crustal Structures
10- Earthquakes , Volcanism and Geohazards
11- Structure & neotectonics
12-Stratigraphy & Sedimentology

REGISTRATION FORM

Submission of Abstracts :
Abstracts Deadline: January 21, 2011.
Acceptance Letters: February 19, 2011
Abstracts should be submitted via electronic mail in MS word format written on Times New Roman font 12. Abstracts should not exceed than 300 words.
Official Language: Arabic and English
Registration Fees: 200 SR.
Students: Free of Charge

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Leadership Development and the Working Environment

By Mohammed A. Al-Khalfan.

Gerald Fitzsimmons, director of Leadership and Talent at the Hay Group speaks about leadership to the Arabian Society for Human Resource Management.

Attending the meeting were, from left, Abdullah Sayyaleh of ASHRM, Fitzsimmons, Fouzi Bubshait, ASHRM's president, Mohammed Al-Khalfan and Hamdi Bata from the Hay Group.

AL-KHOBAR, March 16, 2011 – What differentiates the best business leaders in the Middle East from the rest?

More than 110 members of the Arabian Society for Human Resource Management (ASHRM) heard some answers to that question Feb. 22 at the Sunset Beach Resort.

Gerard Fitzsimmons and Hamdi Bata of the global management consultancy the Hay Group, speaking to the society during its regular dinner meeting, presented a paper on leadership development. The paper is a follow-up to earlier research, which was presented to ASHRM members in 2008.

The study, called "Standing Out," uses first-hand regional data from the GCC and the wider Middle East, including a large sample from Saudi Arabia, to find that the business leaders most likely to achieve sustained growth share certain characteristics.

The Hay Group found that the best bosses are those

> The speakers explored how leaders can learn the behaviors and techniques that will enable them to provide clarity, delegate responsibility and create a rewarding environment for those they manage.

who have a strategic outlook and share their vision with their people. They also give their employees autonomy and responsibility, leaving them free to get on with the job, and they reward fairly and differentiate reward according to performance.

The speakers explored how leaders can learn the behaviors and techniques that will enable them to provide clarity, delegate responsibility and create a rewarding environment for those they manage.

Fitzsimmons spoke about creating a positive working environment, urging guests to think about their best bosses, and the advantages and impact a better working environment can have on business performance. "If you have a good boss who creates a good climate, you work better, you're more engaged, you're more enabled and you're more excited," said Fitzsimmons.

The presentation also explored how leadership can improve to deal with the new post-recession reality and achieve sustainable success. Fitzsimmons said the research reflects the changing expectations of a new generation of employees who have a more global outlook.

He said the GCC especially has seen a demographic change that has a profound impact on leadership. Fast-paced growth over the past decade has accelerated young leaders up the corporate ladder, he said, and the relatively young populations from GCC countries, compared to more mature markets, are increasingly entering the work force.

The research shows a direct link between bosses' behaviors, the environment they create, and productivity and performance. A manager who can adapt, using a range of leadership styles for given situations, will create a better place to work, he said. That, paired with the leadership behaviors discussed in the research paper, can affect employee performance by as much as plus or minus 30 per cent.

The right leadership behaviors, the speakers said, impact employee engagement and ultimately, financial performance.

Employees Develop Cost-Saving Laser Process

By Mohamed Lyzzaik.

Said Al-Jaroudi and Rashed Al-Hadi were two of the three employees responsible for developing an optical laser method for determining total suspended solids in jet fuel.

Amer Al-Shahri helped Saudi Aramco obtain U.S. Patent No. 7,889,337 in February.

TANAJIB, March 23, 2011 – Three Northern Area Technical Support employees' invention has helped Saudi Aramco obtain a patent that will save the company significant time and money in determining the amount of solids in jet fuel.

Said Al-Jaroudi, Rashed Al-Hadi and Amer Al-Shahri's "Optical Laser Method for Determination of the Total Suspended Solids in Jet Fuel" was granted U.S. Patent No. 7,889,337 in February.

The invention provides a method to determine the total of suspended solid particles in a liquid. The method includes providing a liquid sample that includes solids suspended therein, illuminating the solids with a light source, collecting light scattered by the solids and correlating the light scattered by the solids with total solids content.

The determination of total suspended solids (TSS) present in jet fuel is an essential specification. Suspend-

> "The method includes providing a liquid sample that includes solids suspended therein, illuminating the solids with a light source, collecting light scattered by the solids and correlating the light scattered by the solids with total solids content."

ed solids increase wear and tear on precision jet engine parts, clog fuel equipment and cause a range of mechanical engine malfunctions such as filter plugging. Typically, the allowable limit of the total suspended solids in aviation fuel is 1 mg/liter.

Before their invention, the only approved method used to determine TSS present in jet fuels was a gravimetric method that includes filtering the solids. That process is time-consuming, requiring three to four hours per sample. It also requires large amounts of fuel.

Al-Jaroudi, Al-Hadi and Al-Shahri's invention provides laser optical methods and a system for a simple and quick determination of TSS in liquids such as jet fuel.

With their system, routine sample preparation and analysis typically takes about 10 minutes. Also, a statistical method has been employed with the optical method to improve accuracy.

Not only is the new method about 50 times faster than the gravimetric method, it is also simpler. It requires only ordinary glass containers to hold samples whereas the previous method required an expensive metallic container. Also, the analysis technique of the invention can be done on-site and doesn't require the samples to be sent to an outside laboratory.

Cost, too, is significantly less with the new invention. A 95 percent cost saving could be achieved through reduced costs in manpower, sample containers and the size of sample needed. Typically, the gravimetric method costs $81 per sample, whereas the optical method costs only $4 per sample.

Addressing the Real Sustainability Challenge

By Khalid A. Al-Falih, Saudi Aramco President & Chief Executive Officer, at the Second International Energy Forum NOC-IOC Forum.

Paris, France, April 07, 2011

'Ladies and gentlemen, bonjour and good morning. I would like to begin by thanking Secretary General Noé Van Hulst for the opportunity to deliver this keynote address and share my views with such a distinguished audience.

My friends, as we meet today much of the world is grappling with lingering unemployment, the return of re-regulation, and the need to rebalance the economy to promote stability and growth. New patterns of international trade, commerce and investment are emerging. Social and political unrest is engulfing various parts of the Middle East. And while the world struggles with these issues, it was also shaken by last month's devastating and tragic earthquake and tsunami in Japan. For better or worse, we live in a world that is both constantly changing and increasingly interdependent.

Of course, a common thread running through nearly all aspects of today's world is the ubiquitous energy which is so essential for modern life. As we have recently been reminded, such momentous events can have acute impacts on energy, and in turn economic stability, which requires swift and decisive action on the part of energy companies and policymakers alike.

Yet we should not be diverted from our long-term mission and fundamental responsibilities as energy providers by these breaking events, any more than a well-built and well-crewed ship is blown off course by a passing storm. The day-to-day gyrations of the petroleum markets and the news feed rolling across our TV screens should be viewed in perspective and kept in context. So while it is imperative that we demonstrate short-term agility, it would be a mistake to overreact to events in a manner that throws us off course from our future goals.

Therefore, I believe we must work more diligently to articulate and realize a long-term vision for the future of petroleum, both individually and collectively, and whether NOCs, IOCs, service companies, technology developers or EPC contractors. Central to such a vision is a holistic view of the ultimate sustainability of energy and business, including the promotion of prosperity, social progress and environmental protection as well as profitability, which of course is essential for us to meet these other obligations.

Adopting such a view forces the question, "What is the larger public good that we serve as petroleum enterprises?" I would organize the evolution of the industry's response to that question, as well as the expectations of our stakeholders, into three distinct and successive phases.

Early on, many saw the "mission" of oil companies as limited to finding and producing oil, and refining, transporting and delivering products to consumers. Companies therefore simply tried to run their operations as efficiently and cost-effectively as possible in order to preserve their capital and maximize profits for their shareholders.

> … now we collectively need to think about providing energy of all sorts, from all sources and for all kinds of end-use applications, basically for an indefinite period of time.

Next came the growing importance of public health related to our products, environmental safeguards, and the safety of employees and operations—all very positive steps. Yet despite these improvements, the oil industry's contributions to growing the GDP of producing nations, to capacity building, and to overall economic transformation and job creation remained limited. This led to discontent in many producing regions, elevating tensions, undermining trust, and even threatening supplies.

Partially as a result of those shortcomings, today we see the emergence of a third generation of societal expectations which substantially expand the role of petroleum companies in promoting economic development and social progress. In other words, it is increasingly apparent that people the world over are willing to grant the energy and oil industries—and in fact, any industry—a social license to operate only if their business activities have a wider and more positive ripple effect in the markets and communities where they conduct their business.

Such a paradigm requires a greatly extended time frame when it comes to our planning, to ensure the long-term sustainability of our companies and to prepare them for a future which will look very different from our present. In fact, now we collectively need to think about providing energy of all sorts, from all sources and for all kinds of end-use applications, basically for an indefinite period of time.

However, that doesn't mean we should turn away from the imperatives of fiscal discipline, operational excellence and reliability, or producing cleaner products, protecting the environment and providing a safe, secure and rewarding work environment, just so we can chase rainbows. In Maslow's hierarchy of needs, a person who pursues self-actualization still needs food and shelter. Similarly, just because we take on the third-generation challenge, it doesn't mean we should skimp on our day-to-day business activities. Nor am I advocating that we run our companies as altruistic charities or philanthropic organizations: we are NOCs and IOCs, not NGOs, and to meet the various expectations stakeholders have, we must be efficient and profitable. However, I would argue that addressing sustainability in its largest, truest sense is very much in our self-interest as corporations—that there is a clear business case for such an approach if we wish to succeed over the long-term.

In my view, true energy sustainability should be treated as an all-encompassing concept including a wide range of energy, economic, social, technological, and of course environmental priorities. To that end, I see three key imperatives:

• First, creating a practically workable, optimum future energy mix, which also leverages the indigenous resource endowments of nations while addressing the issue of energy poverty in the developing world;

• Second, concurrently securing the adequacy and affordability of energy supplies to meet the rising demands of a growing world population, while maintaining industry profitability; and

• Third, ensuring the acceptability of energy to our communities, by striking the right balance among natural resources, food, water, economic growth and—last but not least— due consideration of environmental protection for our living planet.

By the same token, societies—especially in the developing world—are increasingly convinced that in return for benefiting from their natural resources, both NOCs and IOCs should accept unique responsibilities, particularly when they possess such vast capabilities.

Now, oil companies are called upon to go beyond simply supplying energy or paying taxes and royalties to promoting local manufacturing, maximizing local content, helping build national capacity, assisting in industrialization and economic diversification, and spurring meaningful job creation. These expectations also include helping to raise local education standards, knowledge-sharing and the dissemination of specialized industrial and business expertise, as well as helping to drive scientific research and applied technology development. There are no more easy rides, and no more free lunches to be had—neither for NOCs nor IOCs.

Unfortunately, we can see all too clearly the negative blowback that occurs in societies when these broader considerations are ignored for too long—not only in parts of the Middle East but also in other corners of the globe where the tangible benefits from petroleum have not kept pace with popular expectations.

Let me be clear: I strongly believe that as an industry, our ways of doing business have continued to improve and have benefited the countries and communities where we do business. Many of the policies and processes which have made the petroleum industry so successful can and should be retained. But we should also have the courage to acknowledge that our ways of business have not always kept pace with time, and that we should revisit our concept and philosophy of true sustainability.

In practice, though, what does that mean? Let us begin to answer that question with a look at future energy trends in terms of supply and demand.

Energy consumption in general, and of petroleum in particular, will continue to grow as a result of both demographics and economics. Demand for petroleum will taper off in OECD countries over the next quarter-century, but incremental consumption growth in emerging markets and developing economies will more than compensate for those declines, heralding a fundamental redrawing of the global demand map.

However, while overall energy demand growth is assured, the supply side of the equation is anything but certain. And while fossil fuels will continue to account for an overwhelming share of energy supplies for many decades to come, there is tremendous speculation about the exact nature of the future energy mix and the outlook for shifting source allocations. How rapid will the rise of alternative energy sources actually be? What role will the market play in dictating the pace of those developments, and to what extent will politicians and policymakers "pick winners" through the carrot and stick of subsidies and punitive taxes? How will we strike a balance between the twin imperatives of economic growth and development on the one hand, and environmental stewardship on the other? The answers to those questions will affect all of us—national oil companies and international petroleum firms alike.

> ... while fossil fuels will continue to account for an overwhelming share of energy supplies for many decades to come, there is tremendous speculation about the exact nature of the future energy mix and the outlook for shifting source allocations.

I would like now to take up the topic of the changing roles of these two categories of firms, NOCs and IOCs.

Certainly both have a central role to play in meeting the world's future energy demand. But the optimal roles of various NOCs and IOCs still need to be thoroughly thought through, based on their aspirations, competitive positions, various capacities and available opportunities—as well as a better understanding of a future energy world certain to comprise conventional and unconventional oil and natural gas, clean coal, renewables and alternative sources of energy.

If we are to succeed in that endeavor, though, we need to leave behind outdated modes of thinking and models of cooperation, including broad characterizations that no longer shed much light on reality. For example, the terms "NOC" and "IOC" are useful in describing a firm's shareholder profile—but otherwise the companies in each of those categories vary widely. Traditionally, IOCs have been viewed as talent-rich, technologically advanced and business savvy, while NOCs have been thought of as talent-poor but resource-rich, focused mostly on monetizing natural resources, and being rather unsophisticated in terms of business practices and commercial capabilities. Reality has shifted, though, and today an increasing number of NOCs can match the multinationals in terms of their international reach as well as the strength of both their technology and talent. In addition, specialized service companies are also playing at the leading edge when it comes to new technology, particularly in the upstream.

Of course, the technological, financial and management strengths of NOCs themselves fall along a broad spectrum, they have sometimes radically different business models and operating philosophies, and they conduct their operations on very different scales and in diverse segments of the industry. Some focus resolutely on their home markets, others have interests and operations which span the globe, and some prefer joint ventures in certain segments of their business. Some have robust technical capabilities and develop and operate projects on their own, while others prefer to engage in high-level management of business, assigning engineering and operations responsibilities to third parties. And we should remember that NOCs encompass both producers and consumers. In other words, it is impossible to talk about a "typical" NOC.

However, there are two dynamics that affect every NOC. First, the company must have a clear mandate from its shareholder—in other words, there should be a clear delineation of what that company should do itself, and what it should leave to other entities. Second is the need to align its strategic objectives, core operations and internal capabilities with the needs and expectations of its stakeholders.

In my view, innovative collaboration models are essential in fulfilling any NOC's assigned mandate and meeting the sustainability challenges I mentioned a few minutes ago. I am a strong believer in partnering as a key business strategy and think NOCs of all stripes are best served by extending the hand of cooperation to appropriate partners—whether IOCs, other NOCs, specialized engineering and service companies, research institutes, technology developers, or combinations of these firms. Such partners should complement an NOC's strengths and expertise, bring additional resources and market access, share risk and help to deliver maximum returns to both its shareholders and the wider communities it serves, keeping in mind that such returns should go beyond bottom-line financials.

By the same token, IOCs with open minds, fresh attitudes and flexible and futuristic approaches to cooperation will be more successful in working with their NOC counterparts than more conventional firms—whatever specific shape their collaborative efforts may take. The need for such a new approach is driven in part by the fact that petroleum producing countries are by and large past the stage where their economic and development needs could be met simply through production sharing agreements or royalties and taxes.

As I argued earlier, activities like local economic development, the creation of new employment and professional opportunities, and strengthening local communities are no longer "nice-to-dos," but instead have become "must-haves" for successful and sustainable petroleum enterprises, regardless of their ownership structure or corporate governance model. Such activities are part and parcel of many NOCs' mandates as stewards and producers of their nations' precious mineral wealth, but many of the same expectations are increasingly being applied to IOCs and other foreign investors. In my view, this is what constructive, long-term business relationships will look like in the coming decades.

Let me turn now to specific venues for NOC-IOC cooperation and collaboration.

In addition to the traditional upstream and downstream joint venture, I see many fruitful opportunities for partnership, including human resource development and cross-training; collaborative approaches to pressing environmental issues; and joint research and technology projects, including in potentially substantial areas like the development of tight and shale gas resources.

When it comes to core business activities, there are tremendous complementarities among NOCs and IOCs in various areas all along the petroleum value chain. Saudi Aramco is a strong believer in capitalizing on such mutually beneficial collaborative opportunities, and we are proud of our partnerships with both multinational firms and fellow NOCs; in the Kingdom and abroad; and in sectors ranging from natural gas to refining, marketing, retailing and petrochemicals. In fact, as we speak we are busy developing new joint ventures or expanding existing investments with NOCs like Sinopec and CNPC, PetroVietnam and Pertamina, as well as multinationals like Total, Dow, Sumitomo Chemical and Shell.

Finally today, allow me to refer to our experiences at Saudi Aramco to illustrate these emerging sustainability imperatives in action. We have long been focused on trying to leverage everything we do to promote the development of the Saudi economy and society, because such contributions are an integral part of our corporate mission. Not only is the company the source of most of the Kingdom's national revenue, but it is also the sole supplier of petroleum fuels and feedstocks to

> "Each objective in our downstream strategy is designed to contribute to the nation's prosperity in ways that are tangible, valuable and sustainable, and we are tremendously excited about the enormous potential for growth in this segment of our business."

domestic industries—including petrochemicals, which constitute about 10 percent of our nation's GDP— as well as to utilities, to businesses, and to individual consumers.

In keeping with our obligations to the nation, we focus in the upstream on careful, prudent stewardship of the Kingdom's hydrocarbon resources—a commitment which not only shapes our operational philosophy but also drives technological innovation in exploration and producing. Our long-term ethos is, frankly, a key differentiating factor for Saudi Aramco where we emphasize the long-term management of our reservoirs alongside economic optimization. We view our oil fields as strategic assets to be managed for many decades to come as part of a wider petroleum portfolio, and as a precious national endowment for future generations.

By the same token, the continuing transformation of our downstream portfolio is anchored on adding value to Saudi Arabia's hydrocarbon resources and driving the creation of new jobs—not just in our company, its affiliates or service providers, but also in the conversion, manufacturing and service clusters centered on our integrated refining and chemical facilities. The petrochemical materials we intend to produce have been selected for both their stand-alone economics and their potential to enable new industries in the Kingdom. Each objective in our downstream strategy is designed to contribute to the nation's prosperity in ways that are tangible, valuable and sustainable, and we are tremendously excited about the enormous potential for growth in this segment of our business.

In addition, we are investing in new R&D initiatives involving both upstream and downstream technologies, on our own and in conjunction with universities and other research institutions in the Kingdom and abroad. Building on our strong legacy of community involvement and corporate citizenship, we are also committed to helping create a knowledge-based economy in the country, to pooling our expertise and experience with that of other organizations, and to strengthening the capabilities of local firms engaged in energy activities and process industries in general.

Of course, these activities are possible only because for many years we have invested in developing our human resources for the long term. Every year we enroll thousands of Saudi Arabia's brightest into our own vocational programs and sponsor many of them for university studies at home and abroad. We have a strong professional development program which emphasizes mentoring and on-the-job experience, in addition to a strong culture of self-development among our work force. Visitors to the company often tell us they are first struck by the size and scale of our facilities, but leave talking about the sophistication of our technology and above all the quality of our people.

In short, we recognize that the impact of our work and our responsibilities to our stakeholders do not stop at the gates of our refineries, gas plants and petrochemical complexes or the perimeters of our producing fields. Rather, we believe that Saudi Aramco has an obligation to contribute to the Kingdom and its people in many ways both direct and direct, and that serving as a catalyst for the development and further diversification of the domestic economy is an inseparable aspect of our mandate as an organization. At the same time, our social and economic contributions do not come at the expense of our focus on efficiency and the profitability of our business, but rather these factors complement one other and are all essential for long-term business survival and sustainability. In my view, this is the future model that most countries—especially developing nations—aspire to see not only from their own national oil companies but from all of their investors, both local and foreign.

In conclusion, I am of the strong belief that we need to approach the future with more open minds, to better define our future trajectories as individual companies, and to develop more fruitful models of cooperation which create more powerful synergies in our interactions. Above all, we need to consider the hopes, aspirations and expectations of our stakeholders—not as peripheral concerns but as central elements in our business strategies, and to address the sustainability challenge of the social and economic development of our communities alongside business profitability and environmental protection. There are many variables and unknowns ahead, and there will be both welcome and unwelcome surprises that lie in wait. But one thing is certain: the oil business of the future will not be like that of the past, any more than the expectations of the societies we serve will resemble the needs and desires of previous generations.

Thank you for your attention this morning.'

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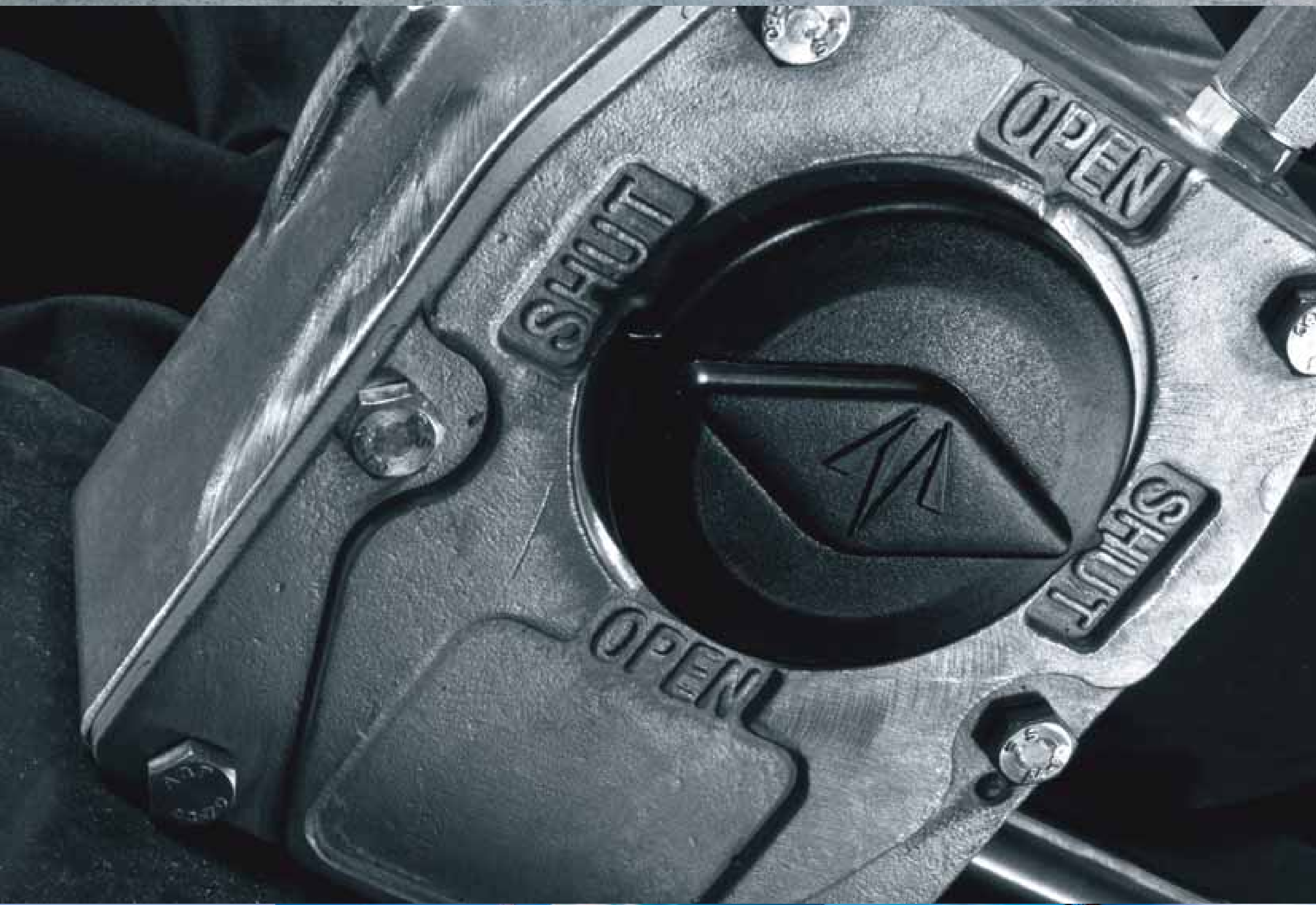

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International Cooperation at the New Stage of Economic Globalization

By Khalid A. Al-Falih, Saudi Aramco President & Chief Executive Officer.

Beijing, China, March 21, 2011

'Ladies and gentlemen, *zao shang hao* and good morning. Let me begin by expressing my admiration for the amazing development of the Chinese economy and the increasing prosperity of the Chinese people.

Today, the air in China's major cities is cleaner than it was a decade ago, and there is a rising sense of environmental stewardship and civic responsibility among its people. Wherever one looks one sees world-class infrastructure and facilities. This country is now the engine pulling the global economic train, and China is engaging in a diverse range of international economic relationships marked by new investment and trade flows and greater integration.

Since I come to you from Saudi Arabia, an island of calm amid the turmoil sweeping the Middle East and North Africa, I can tell you that much of that turbulence is grounded in economic factors and a lack of opportunity, especially among young people.

Therefore, I also feel compelled to commend the foresight and wisdom of the Chinese leadership's vision of a "harmonious society," where progress is measured not just by headline GDP growth or increasing national revenue, but also the rising prosperity of the people, the creation of economic opportunities across the nation, and greater societal balance and social harmony.

This is also what the Middle East needs, and I believe our friends in China, as well as other partners around the world, can be part of that necessary transformation through greater economic integration and investment, as I will explain in a moment.

Certainly as China sees the increased prosperity of its own "harmonious society," there will be an increasing emphasis on the adequacy of energy supplies. At Saudi Aramco, we strongly believe China – like other major global economies – can best pursue energy security, promote sustainable and balanced economic development, and protect its precious natural environment by drawing upon a diversified energy portfolio centered on proven fossil fuels suitably complemented by renewables and alternatives. Allow me to elaborate.

Coal is a plentiful indigenous resource which accounts for about seventy percent of all Chinese energy consumption, and it will remain important for many decades to come, even as China switches to less carbon-intensive energy sources. China has worked diligently to improve the environmental performance of coal use, through its cleaner, more efficient coal-based power plants. Looking to the future, I also see considerable potential for carbon capture and sequestration to play its part in mitigating greenhouse gas emissions from energy use.

Meanwhile, I am pleased to see China's increasing interest in cleaner natural gas – especially given recent technical breakthroughs related to shale gas and its potential exploitation in this market. China has significant shale gas resources, which is heartening as its gas

> China has worked diligently to improve the environmental performance of coal use, through its cleaner, more efficient coal-based power plants.

consumption is set to increase this year by more than 20 percent, according to CNPC research.

At the same time, contributions from renewable energy sources will certainly expand, though we need to be realistic about their gradual pace of growth. Furthermore, these sources start from a very small baseline, given that non-hydro renewables currently meet less than one percent of China's energy needs.

Therefore, I believe fossil fuels – including clean coal, natural gas and oil – will remain pivotal for the foreseeable future. Oil alone now satisfies nearly a fifth of China's energy needs, and accounts for virtually all the energy used in transportation and petrochemicals. Therefore, oil will remain a significant part of China's energy mix, even with the emergence of alternative propulsion systems.

In fact, the NDRC estimates China's oil demand will approach 12 million barrels per day by the end of the decade, up from about nine million bpd at present, as China's people enjoy the benefits of more affluent and more mobile lifestyles.

But just as China continues to rely on oil to meet its growing energy needs, the oil industry itself looks to China as the largest source of incremental demand growth, so there is a mutually beneficial and strategically important relationship between China and the world's petroleum producers.

As we all know, some analysts like to single out the impact of China's demand on world oil markets. To the contrary, I believe increased Chinese demand offsets declining consumption in the OECD nations, and is essential to encouraging necessary investment in exploration as well as oil production, refining and transportation capacity, which ultimately benefits all petroleum consumers.

Certainly the development of global partnerships is a significant factor in achieving an optimal energy portfolio, and here I would like to congratulate China's energy sector – in particular its leading petroleum enterprises – on the steps already taken.

In addition to making sustained investments in resource-rich regions and in sectors ranging from energy

> "China has worked diligently to improve the environmental performance of coal use, through its cleaner, more efficient coal-based power plants."

and natural resources to construction and large-scale infrastructure, China has also brought us closer together by opening its domestic market to strategic foreign investors like Saudi Aramco.

These policies reinforce the mutually beneficial interdependence that characterizes our bilateral relationship – an "energy superhighway," you could say – and we look forward to the increased deregulation that will improve the profitability of major investments by energy companies in China, and to encourage more such ventures.

Ladies and gentlemen, much of China's vast surplus has been invested in overseas financial instruments, and I believe some portion of that capital could profitably generate even greater benefits if it were directed to opportunities like industrial development initiatives, including overseas investments in manufacturing and services projects.

I strongly believe China can be the global investor, because in addition to capital, this nation also has world-class capabilities in engineering, technology development, industrial services and project management. Rather than being a net recipient of FDI, technology and expertise, you have opportunities to extend your capital and industrial know-how to countries where China is already investing in natural resources and extractive industries.

This would not only help these nations industrialize, add value, create jobs and diversify their own economies, but also secure those markets for Chinese goods and services, cement bilateral and multilateral partnerships, enhance global economic integration and promote economic stability – all serving to foster a kind of "harmonious global community."

There are also attractive opportunities for mutually beneficial cross-investments – including in Saudi Arabia, which is in the midst of a five-year development program worth some 450 billion dollars and encompassing world-scale projects in many sectors.

However, such investments would simply be an extension of the existing close bonds between the People's Republic and the Kingdom, including Saudi Aramco's own linkages with China's petroleum sector.

Our relationship is founded on the provision of steadily growing volumes of crude oil – currently about a million barrels per day, making Saudi Aramco China's largest and most reliable supplier.

In this regard, the Kingdom has been and will continue to be a calming influence in global oil markets – particularly in times of market turbulence, when it can tap its substantial spare capacity to make up supply shortfalls elsewhere.

But our collaborative ties with China also include our existing joint-venture partnerships with Sinopec in both Fujian Province and Saudi Arabia – a perfect example of cross-investment – as well as our acquisition of a widening range of quality goods, high-tech equipment and specialized industrial services from China.

Along with our friends at the NDRC, Sinopec and CNPC, we continue to pursue prospects for other future investments in China. The model of integrated investments which extend across the value chain has proven to be a success in our Fujian joint venture, and Saudi Aramco is looking to replicate the right ingredients for similar profitable JV opportunities in China.

In fact, just this week, these efforts bore fruit as we signed two agreements with the leading Chinese petroleum enterprises: an MOU with Sinopec for investment in our Red Sea Export Refinery at Yanbu, and another MOU with CNPC for us to invest in a refining project in Yunnan Province. We look forward to working closely with our partners on these ventures, and to realizing the mutual benefits of these world-scale projects.

Ladies and gentlemen, perhaps most important for the future are our people-to-people contacts, which continue to grow and deepen. Every year we send some of our most promising young people to Chinese universities both to master a technical discipline and to learn about your nation and its culture, society and people.

I would also note that young Chinese men and women make up the largest group in the newest intake of students at the King Abdullah University of Science & Technology, Saudi Arabia's groundbreaking graduate-level research university, which was built by Saudi Aramco.

Ladies and gentlemen, let me close by recapping my five key messages. First, China is best served by a diverse and robust energy portfolio which relies primarily on fossil fuels while developing alternatives at a realistic pace.

Second, far from undermining security of supply, rising Chinese oil demand promotes essential investments by the petroleum sector.

Third, more expansive and diverse strategic foreign direct investments by China will deepen relations between this nation and its international partners.

Fourth, people-to-people contacts will remain the essential foundation for a deepening relationship.

And finally, Saudi Aramco's relationship with China is very much a two-way street, and as we work with our partners to establish more joint ventures here, I look forward to even more traffic and trade—including additional Chinese investments in Saudi Arabia—along the "energy superhighway" connecting our company with this great nation. *Xie xie.'*

The Evolving Role of Finance and the Need for Top Talent

By Abdullatif A. Al-Othman, Senior Vice President, Finance, Saudi Aramco.

Keynote Remarks at the First Saudi Financial Professionals Forum.

'Dr. Ahmed Al Mogames, distinguished guests, and fellow finance professionals:

It is with pride and joy that we witness the launch of the First Saudi Finance Professionals Forum. Saudi Aramco is honored to join the Saudi Organization of Certified Public Accountants in sponsoring this program. This forum is unique in that it brings together those of us who desire to nurture and develop finance professionals and the finance profession in Saudi Arabia: executives, accountants, auditors, investment professionals, analysts, and academicians. Nothing could be more timely – indeed, more urgent – than launching this effort to increase the quantity and quality of financial professionals in the Kingdom.

In today's economy, financial professionals from around the world are being called upon to serve not only in technical roles, but also to contribute in central roles of strategic planning, innovation and management. During recent years, corporate finance organizations have been transforming to tackle the complexities and challenges of our evolving environment. Improvements in technology and the drive to reduce costs and cycle times led to process efficiencies. Major international business scandals and resulting regulations led to an increased focus on governance. More recently, finance organizations have been challenged to not only provide data, but to provide analysis and insight to enhance business decisions – measure corporate performance – and engage in strategy formulation. What we've witnessed is a change in the expectations placed on us as finance professionals.

Here in Saudi Arabia, the nation is driven to attain and sustain rapid economic growth and diversification in order to provide quality jobs for our fast-growing population. At Saudi Aramco, we are focused on transforming our enterprise into a global powerhouse not only in upstream oil exploration and production, where we lead the world today, but also deeper downstream into petrochemicals and specialty chemicals, fostering the creation of vibrant conversion industries.

A major portion of Saudi Aramco's future business portfolio will be in joint ventures with multinational companies. Already Saudi Aramco is partnering within the Kingdom – and globally -- in the areas of refining and petrochemicals. These joint ventures require new kinds of expertise, including the skills for interfacing with financial reporting requirements of partners firms, their public shareholders and home government regulators.

Saudi Aramco also launched an Entrepreneurship Center to train Saudi citizens in the skills for success in business creation, and to incubate and nurture home-grown small and medium technology-oriented enterprises.

> "In today's economy, financial professionals from around the world are being called upon to serve not only in technical roles, but also to contribute in central roles of strategic planning, innovation and management."

The Kingdom's economic development is all about creating value and making the right investments. This is at the heart of what finance professionals do and that is why we need to seize this opportunity of exciting challenge and prepare a leading cadre of finance professionals.

Today's generation of financial professionals in the Kingdom will have exciting opportunities not only to carry out traditional responsibilities such as budgeting, cost containment, and financial reporting, but also strategic management roles in long-term planning and risk management. Surveys by the Corporate Executive Board indicated a dramatic change in just one decade: in 2000, 83 per cent of global finance executives surveyed stated accounting and auditing as the most essential skills for financial professionals. Ten years later, responding to the same questions, only 21 per cent of executives ranked accounting and auditing as most essential. Thirty-eight percent said leadership was the most essential, while 17 per cent indicated statistics and modeling and 8 per cent indicated "deep industry knowledge."

As the world progresses into the Knowledge Economy, finance professionals are moving ever closer to the center of the leadership stage, because financial professionals are knowledge workers par excellence. Mastering finance is like mastering a language – a language both versatile and precise to describe and project business risk and reward, goals and results.

Mastery of the financial disciplines needs to be complemented with soft skills such as communications, advocacy and influence, and leadership, coupled with business knowledge of the industry you are in.

To address this challenge, I believe we need to work together on creating the right ecosystem for nurturing the best financial professionals and financial industry. This can be summarized in five points.

First is addressing the pressing need for improving education of our youngest citizens. Attaining stronger math and science ability is vital if we are to have a large, strong generation of homegrown financial professionals. We want to align these efforts of ours with those of all the members of financial professions in the Kingdom.

A second area is the opportunity for finance professionals to collaborate with institutions of higher education. Throughout the Kingdom – and across the spectrum of businesses – there is a demand for young Saudis with finance-related degrees.

Saudi Aramco's financial professionals look forward to joining with other financial professionals in the Kingdom in partnering programs with the nation's universities. Together, we can provide insight to ensure that curricula include courses and experiences that will promote and enhance business and finance knowledge and development of basic soft skills and competencies. Members of our profession can send subject matter experts to supplement the classroom learning experience by teaching and sharing relevant experiences. We also can provide structured internships with clearly communicated expectations and agreed upon goals, objectives, and measures of performance. Effectively, we can function as mentors before students graduate to the professional workforce.

Early on-campus engagement provides an additional benefit to employers in the Kingdom. Through classroom interaction, including students in professional forums, and internships we have the opportunity to identify top students prior to graduation.

Our third common challenge is in promoting a desire to pursue lifelong learning, training and continuing education throughout the careers of the Kingdom's financial professionals. As great as the investment in early and higher education must be pre-career, lifelong learning is what changes everything. Lifelong learning is not about merely having diplomas, certificates, technologies, and skill sets. Lifelong learning in our discipline is about being financial professionals as a way of life. In every business in the Kingdom, not only is it essential to have robust programs of formal training and continuing education for professionals. It also is essential to foster a culture of mentoring.

A fourth opportunity we should pursue to build on an already strong financial system and continue to expand it, advancement of secondary market, custody, trust laws as well as Islamic Finance are all ripe to play critical role in taking our financial market to higher levels.

Fifth, each of you, and each member of the next generation of Saudi financial professionals is called to leadership in business and in society. As I mentioned earlier, your success as leaders depends on your skill and devotion at communicating, educating, and interpreting financial matters to your business associates or clients. Financial professionals also are indispensable for business objectives of operational excellence and change management. We should broaden our knowledge and look at business issues from its multiple angles. A major component of change management is keeping ahead of the curve in understanding rapidly changing technologies as they affect the way we do business.

The capstone virtue for leadership is ethical integrity. Financial professionals must recognize the terrible damage caused to the world economy in recent years by unethical financial practices. By embracing prudence and honesty, we can strengthen our national economy and contribute to a sustainable world economic recovery.

Each of you, and every member of the next generation of Saudi financial professionals, will bear a solemn responsibility to protect our businesses and public institutions from undue financial risk. Your specialized financial training will make you often uniquely valuable to your employers or clients in this regard. Paradoxically, in order to protect society and businesses from hazardous risk, you often will have to take personal risks.

It could be risky to your career when you give your honest judgment and say "no" to a powerful and ambitious person who is determined to hear "yes" to a pet project. You may face personal risks when you take firm measures to prevent or expose fraud and corruption. Remember, the financial professionals who bear responsibility for much of the world economic crisis of 2008 were lacking neither in the tools nor in the specialized knowledge of finance. But they were deficient in moral courage and prudence, in the practical wisdom that is sound management.

> As the world progresses into the Knowledge Economy, finance professionals are moving ever closer to the center of the leadership stage, because financial professionals are knowledge workers par excellence.

It is exactly the spirit of personal risk – of giving yourself to your profession – that makes the difference between having tools and skills and being what you are called to be – true professionals.

Let me close with a word about the genesis of this forum. The finance department of Saudi Aramco conducts frequent orientation programs for new employees – including new hires to the company from the Kingdom or abroad, and employees transferring to finance from other business lines. Each orientation program includes team-building exercises and development of initiatives to improve the work of the company. A team-building exercise devoted to corporate social responsibility was the genesis for this Forum.

In other words, we owe the existence of this forum to a group which, by its very nature, took a fresh look at things and proposed an initiative from the grassroots. That is the same sort of spirit that energizes our gathering today. With the capable partnership of SOCPA and the other professions represented here today, I am confident that Saudi financial professionals can build a strong and durable team, always fresh and innovative in outlook, to increase and sustain economic value in our Kingdom.

It is with pride and satisfaction that this inaugural forum was launched. I hope that the finance leaders of our community will step forward to ensure that there will be future forums that will bring us, and other finance professionals, together to share our knowledge and experiences as we nurture the development of our profession in Saudi Arabia.

Thank you.'

Giga-Cell Simulation

By Dr. Ali H. Dogru, Saudi Aramco.

Reprinted from the Saudi Aramco Journal of Technology.

Abstract

High resolution geological models built using seismic, geological and engineering data are often upscaled to smaller size flow models for reservoir simulation. It is well-known that reservoir heterogeneities play a very important role in reservoir behavior. Due to upscaling, these heterogeneities are lumped into average rock properties. Therefore, upscaled simulation models only provide average reservoir performance rather than actual performance.

In general, vast amounts of seismic, geological and engineering data are available for the large reservoirs of the Middle East. If high resolution seismic data is used, these geological models could be in the order of billions of cells. In practice, due to the limitations of reservoir simulators, these high resolution models are often upscaled to flow models of a few million cells. This article presents a new parallel reservoir simulator, Giga-POWERSTM, which runs geological models with or without minimal upscaling. The world's largest oil reservoirs with long production histories can now be simulated using over 1 billion cells in practical time spans. This technology provides highly detailed pictures of the activity inside the reservoirs capturing the movement of fluids. It is a very powerful tool for designing new production scenarios to recover every last drop of oil using the most cost-effective means.

Introduction

The world's largest oil fields are located in the Middle East. Saudi Aramco uses reservoir simulation technology to manage its vast hydrocarbon reservoirs and had relied almost entirely on commercial simulators until 2000. Figure 1 shows the average number of grid blocks (cells) used for the earlier black oil simulation studies. As shown, the number of blocks started in the vicinity of 10,000 cells in 1988 and reached 150,000 by 2000. The average grid block size varied between 1 km and 0.25 km with the vertical number of layers ranging from 10 to 15. These were highly upscaled models taken from the geological models that contained several million cells and far more detail. This time period is referred to as the "Kilo-Cell Simulation Period."

In 2000, with the introduction of Saudi Aramco's new, in-house parallel reservoir simulator, POWERS (Parallel Oil, Water and Gas Enhanced Reservoir Simulator)1, the model size increased to over 1 million cells. The average grid cell size was less than 0.25 km, with a minimum of approximately 0.08 km (80 m). The number of vertical layers also increased from 10 to 100. These high resolution models were used in relatively small fields, and they were proven to be more successful for locating bypassed oil and guiding engineers to drill in specified locations to recover more oil[1, 2]. This time period is the "Mega-Cell Simulation" period.

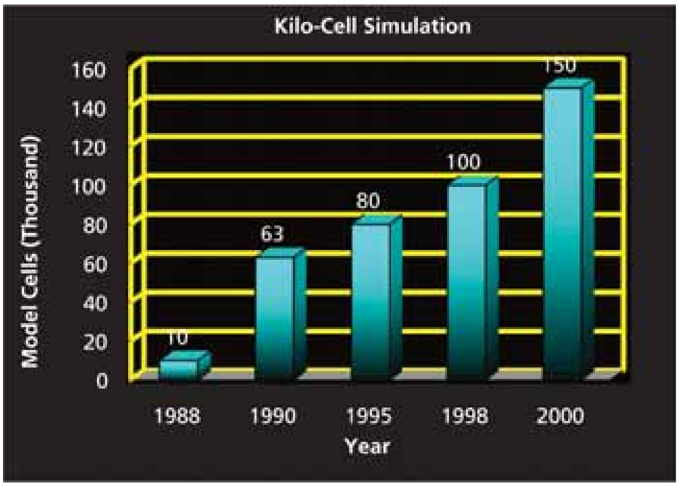

Fig. 1. Kilo-cell simulation.

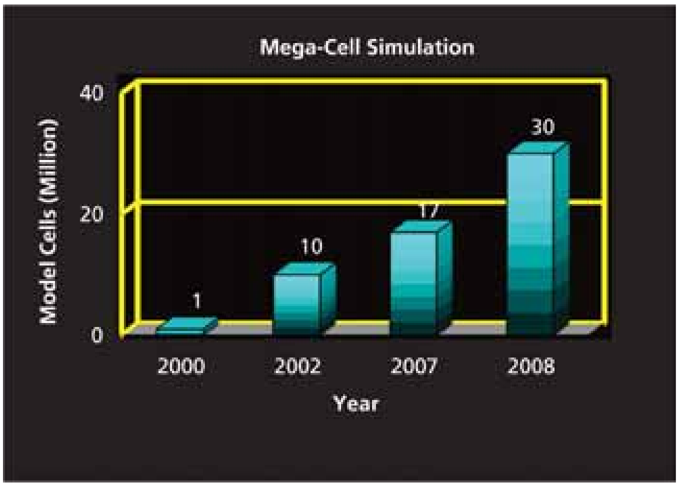

Fig. 2. Mega-cell simulation..

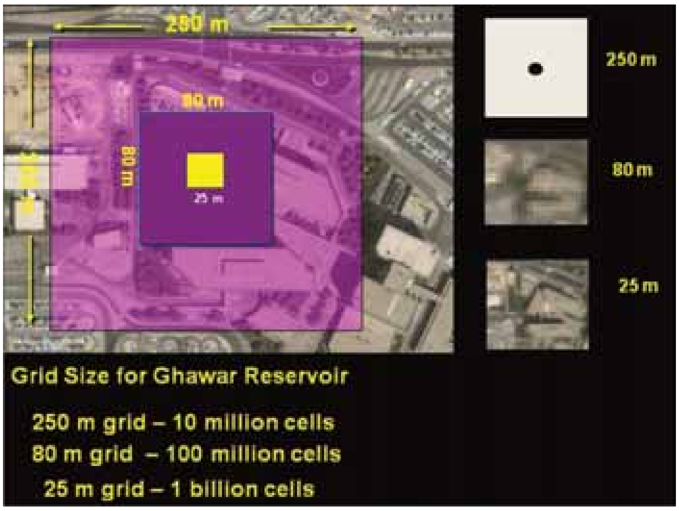

Fig. 3. Concept of effect of areal grid size on capturing reservoir heterogeneity.

Need for Giga-Cell Reservoir Models

Many large fields were simulated over the past decade by mega-cell simulator technology, Fig. 2, and used the associated pre- and post-processing capabilities during the past decade. The number of cells for the black oil simulation increased 30 times during the past decade to 30 million cells.

This technology still lacked the capability to provide seismic scale simulation models for the world's largest onshore and offshore reservoirs. To simulate large reservoirs like Ghawar Arab-D at a seismic scale, a new technology – a new, more powerful parallel reservoir simulator – was required. Simulating the world's largest oil reservoir with sufficient resolution would have significant economic impact. With fine gridding, high resolution models of large reservoirs can be simulated accounting for log scale and seismic scale heterogeneities. This would mean a highly accurate reservoir description that captures seismic and log scale heterogeneities, and therefore opens the door to designing new, more precise recovery schemes to recover more oil.

Figure 3 illustrates the role of areal grid size when capturing reservoir heterogeneity. As shown, an areal square grid of 0.25 km (250 m) covers an area composed of

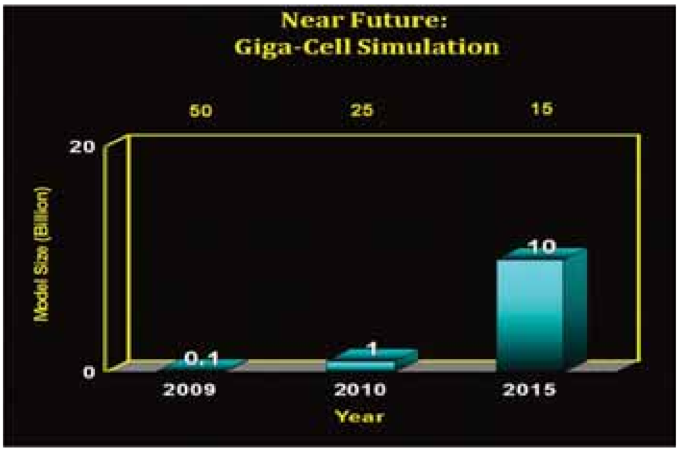

Fig. 4. Trends for giga-cell simulation..

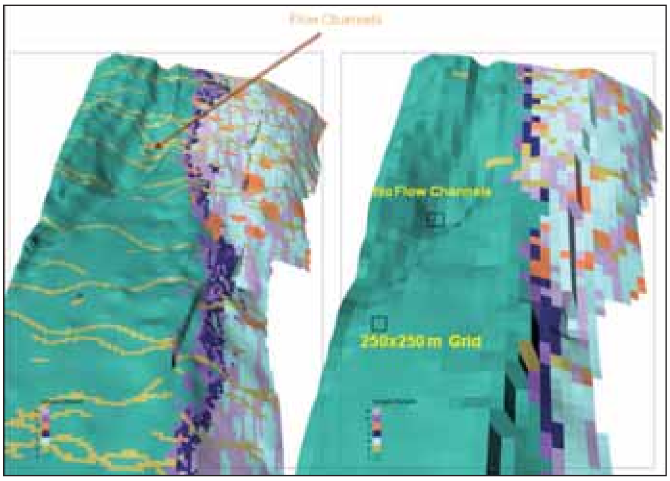

Fig. 5. Areal view of geological model (left) and upscaled simulation model (right).

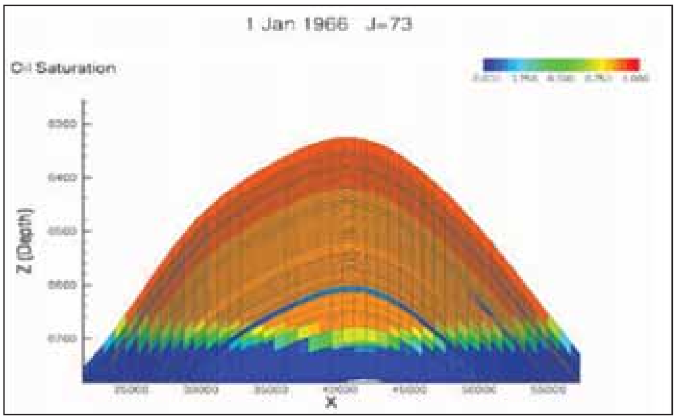

Fig. 6. Near log scale vertical layering.

two large office buildings and a parking lot, walkways, trees and garden. Such a large area is represented by a single dot when used as a grid block, as illustrated by the square with a dot in the middle in the top right corner of the figure. In terms of reservoir simulation, this means that any rock heterogeneities within this block are indistinguishable; all the heterogeneity is averaged to a single value (e.g., one permeability value). Using this grid size would require 10 million cells to simulate the entire Ghawar Arab-D reservoir with 32 vertical layers.

If the grid block size is reduced to 0.08 km (80 m), the grid will cover only about two office buildings. The grid block figure on the right shows that conceptually the block can contain more information, i.e., a better image. If the areal grid size is 0.08 km, 100 million cells would be required to simulate the entire reservoir with the same number of vertical layers.

If the grid block size is further reduced to 0.025 km (25 m), which is equivalent to seismic scale, the image becomes much clearer. Conceptually, this means that a 25 m simulation grid can capture more reservoir heterogeneity. This would require 1 billion cells to simulate the entire reservoir.

The next generation of POWERS, the new giga-cell

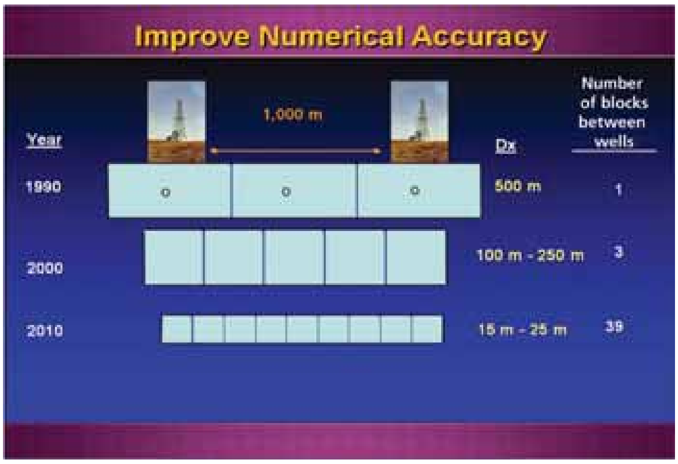

Fig. 7. More cells between the wells results in fine grid models.

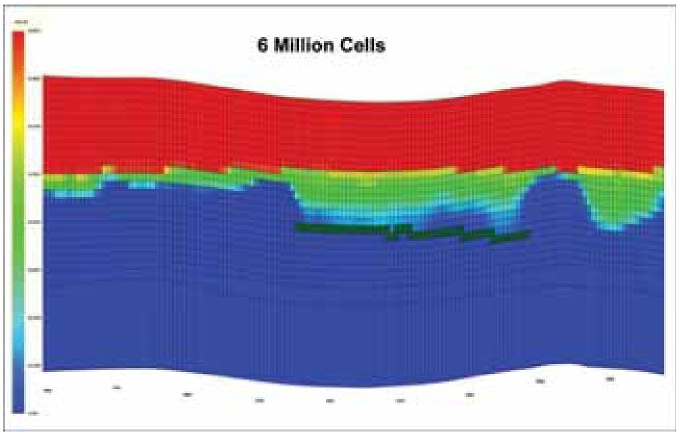

Fig. 8. A coarse grid model with 6 million cells indicating a gas cap breakthrough at a horizontal well after 2 years of production.

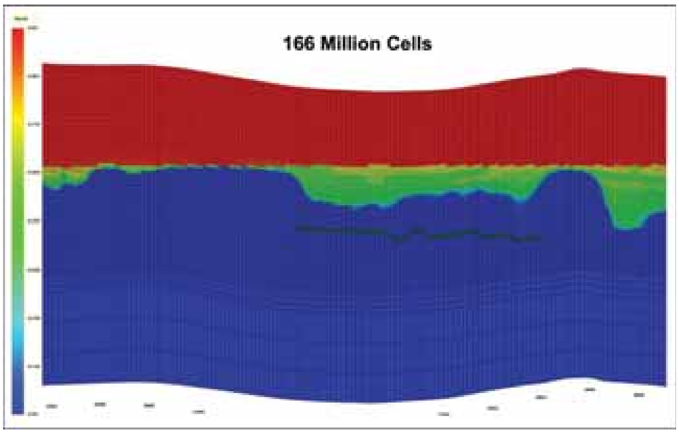

Fig. 9. Fine grid model with 166 million cells showing no gas cap breakthrough at the horizontal well after 2 years of production.

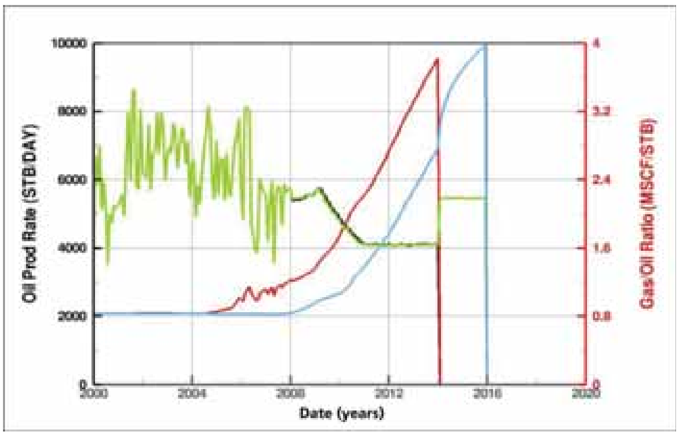

Fig. 10. Simulated well performance comparison using coarse grid (66 million cells) shown in red and fine grid (166 million cells) shown in blue. The fine grid model reveals longer production time.

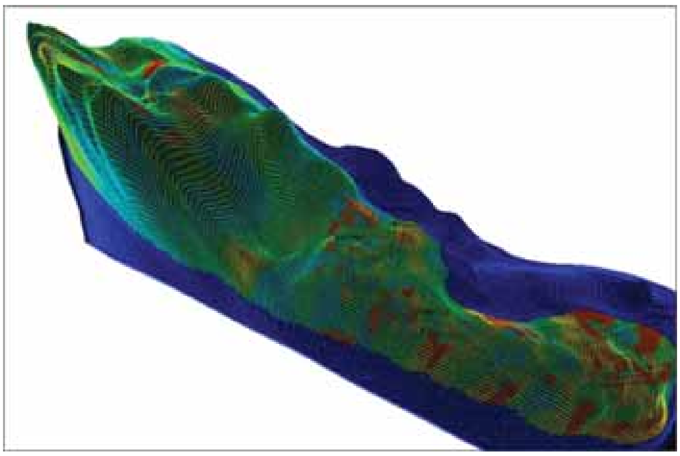

Fig. 11. Largest offshore oil reservoir in the world simulated in over 1 billion cells.

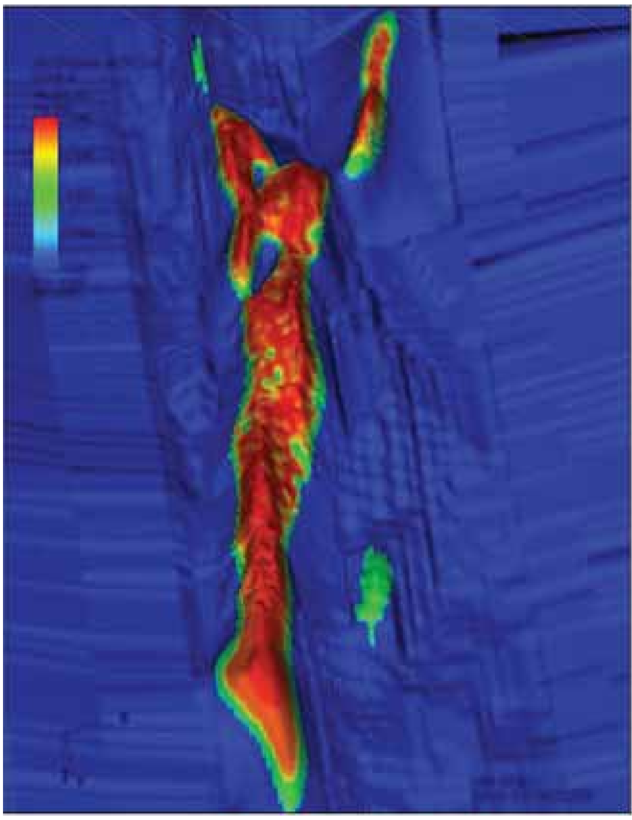

Fig. 12a. Giga-cell simulation of the largest onshore oil reservoir in the world.

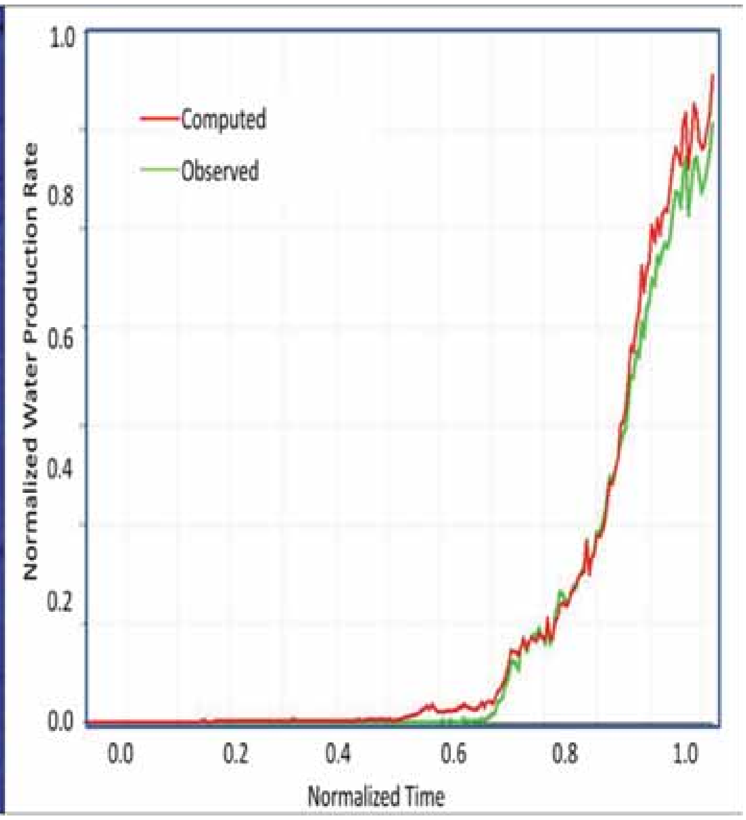

Fig. 12b. Water cut match of Ghawar field by GigaPOWERS.

parallel simulator, GigaPOWERS, succeeded toward this end[3]. That journey and the early trial of two giant reservoirs simulated by an excess of 1 billion cells for the first time, covering the entire production history of 60 years and involving many producer and injector wells, has been documented[4]. The reservoirs were simulated in seismic grid size (15 m to 42 m) within practical simulation times (15 hours to 32 hours). Technical issues were solved and smoothed out, and the official user version of GigaPOWERS was completed and launched in January 2010[3]. The simulation time required continues to be reduced with new cluster computers and is expected to decrease even further. The immediate target is to reduce it to eight hours – or an overnight run.

These examples and capabilities illustrate the early work of the "Giga-Cell Simulation" period. Figure 4 presents a projection for the future model size in terms of black oil cells.

Benefits of High Resolution Simulation Models

Fine grid high resolution models result in two major types of benefits: (1) Reduced or eliminated upscaling, and (2) Higher numerical solution accuracy due to smaller grid size.

Benefits Due to Reduced or Eliminated Upscaling

Areal Resolution. As mentioned earlier, representing reservoir heterogeneity in reservoir models is essential. If this is not accomplished and simulations are built

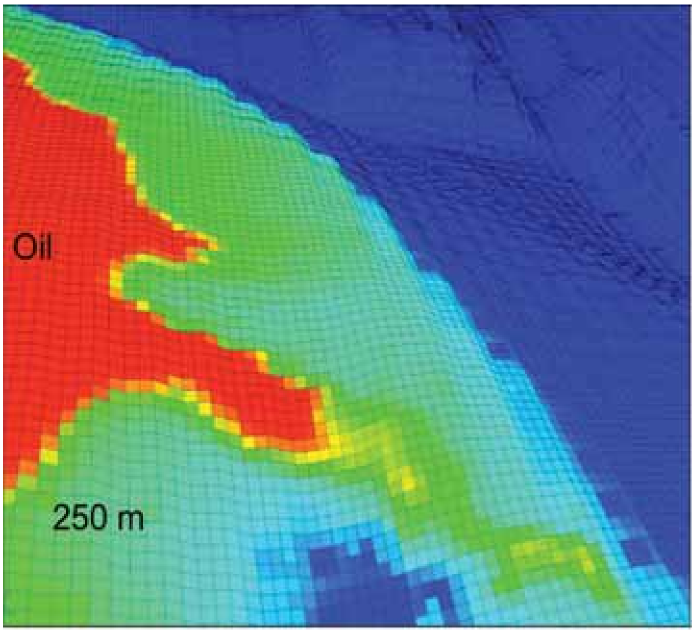

Fig. 13a. Mega-cell simulation – Saturations.

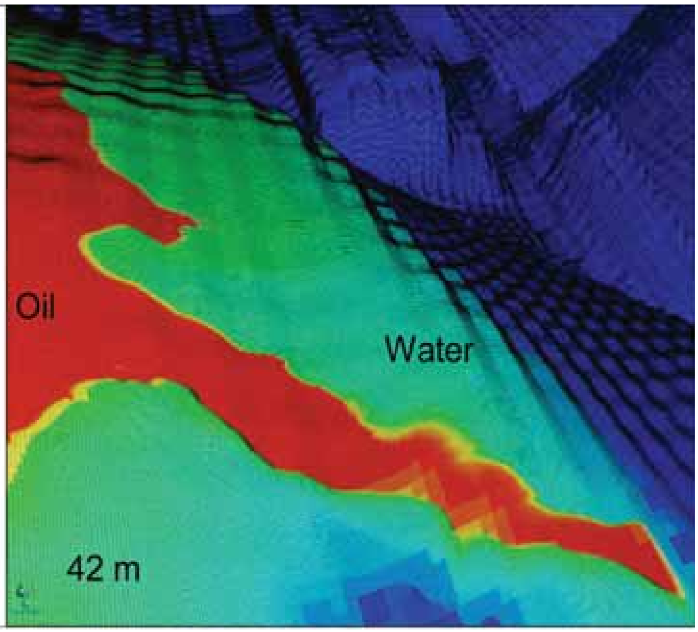

Fig. 13b. Giga-cell simulation – Saturations.

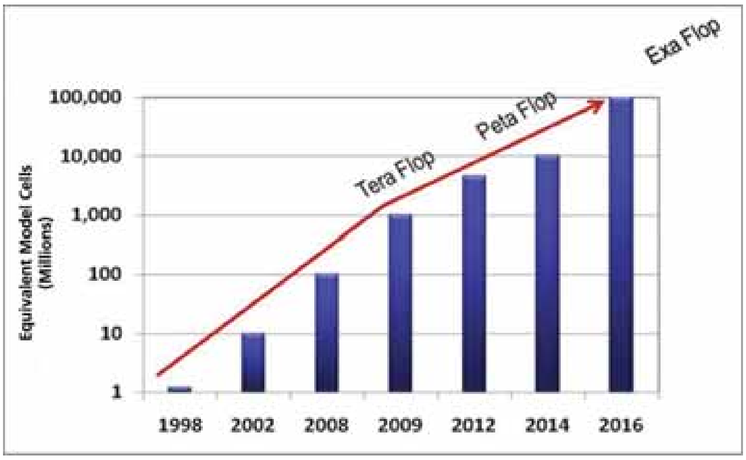

Fig. 14. Past and predicted growth trend of model size with increasing computational speed.

on averaged reservoir properties, the result produced by the simulator reflects an averaged reservoir performance. Specifically, fluid movement between wells is largely misrepresented by the upscaled models. Although measured properties, such as well pressures, water cuts and gas-oil ratios (GORs), can be matched at wells with the upscaled models, the distribution of oil and water within the reservoir (between the wells) cannot be matched with upscaled models unless the reservoir heterogeneity is properly represented in the reservoir model.

Figure 5 shows that flow channels in the geological model disappear in the upscaled model using a 0.25 km areal grid. Obviously, the upscaled model cannot adequately simulate the fluid flow in channels specifically, and throughout the reservoir in general.

On the other hand, if the geological model can be simulated intact, using as many cells as required to maintain the integrity of all data, the resulting reservoir model would adequately capture fluid flow within the reservoir for more accurate reservoir management.

Vertical Resolution. High resolution, fine grid models should have a sufficient number of vertical layers to capture vertical heterogeneity. Ideally, log scale layering[2] in the order of one foot, would capture all the vertical hetero geneity; however, this increases the computer time. Therefore, proper upscaling can be applied to select layers while still capturing vertical heterogeneity. This is important in capturing advancing water and gas fingers and similar fluid movements inside the reservoir. Figure 6 shows an actual field case where near log scale vertical layering was selected.

Benefits Due to More Accurate Numerical Solution (Fine Grid)

An accurate numerical solution is important in calculating the movement of water and gas inside the reservoir. For example, when large grid blocks are used, pressure fields in the reservoir cannot be accurately generated. This will affect the fluid velocity fields, which are computed from the pressure solution. Large blocks will smear the advancing fluid fronts, often predicting premature fluid breakthrough at the wells[4] due to a well-known phenomenon called numerical dispersion. To match the water and gas arrivals at the wells, reservoir engineers often introduce pseudo-relative permeabilities (and have to introduce permeability modifications), which could be unrealistic.

For example, for a 1 km well spacing, only one grid block can be placed between the wells if a 0.25 km sized grid block is used. The pressure field calculated by this approach will not show any sharp drop at the well cells, but instead averaged pressure values will be calculated for the three cells, Fig. 7.

On the other hand, if finer and finer grids are used, more cells can be placed between the wells, and therefore true pressure profiles between the wells can be captured that are closer to the reality. The sharp pressure drop at the well cells can be better computed by the fine grid model. For example, Fig. 7 shows that for a billion cell model of the largest oil fields, we can place nearly 40 grid blocks between the wells. This provides a higher numerical accuracy for the pressure and saturation solutions, and thereby well pressures, water and gas breakthroughs can be calculated with accuracy.

Examples

Figure 8 illustrates that a 6 million cell simulation model predicts that a horizontal well located away from a gas cap will encounter gas breakthrough in 2 years. Consequently, when the model is refined, both in an areal and a vertical direction, resulting in a 166 million cell model (with 28 times finer grids), Fig. 9, no gas breakthrough is calculated after 2 years of production from the horizontal well. This example clearly demonstrates the effect of numerical dispersion.

Obviously if the simulator is fast, the 166 million cell model should be the choice for these reservoir studies.

The net effect on the well performance is presented in Fig. 10 where the computed production rate (left axis) and GOR (right axis) are plotted against time for the two different models. The production rates for the coarse grid (66 million cells) and fine grid (166 million cells) are represented by black and green colors, respectively. The GOR behaviors for the coarse and fine grid models are represented by red and blue colors. Figure 10 also shows that for the coarse grid model production (black), the well is shut-in as the GOR (red) reaches a maximum (user specified criteria) near 2014. On the other hand, the fine grid production rate (green) goes to zero (well is shut-in) at 2016 when the GOR (blue) reaches a maximum value. When the two cases are compared, it is seen that the fine grid model would yield an additional 2 years of production at a higher rate than the coarse grid model.

Billion Cell Examples

GigaPOWERS[3] has succeeded in simulating the world's largest offshore oil reservoir, Safaniya, in its entirety, with 1 billion and 8 million cells incorporating 60 years of production, Fig. 11. The areal grid size was 15 m on the oil-water system reservoir in a run made on a cluster computer using 2,000 cores and performed in only 15 hours.

The largest onshore oil reservoir, Ghawar, was also simulated as a full-field model using 1 billion and 32 million active cells, Fig. 12a. This was a three-phase black oil simulation run. Again, using 4,000 cores of a cluster computer, the GigaPOWERS simulator completed the run in 21 hours incorporating 60 years of production history involving many production and injection wells. Total field water cut match for the first giga-cell run (prior to history matching) is shown in Fig. 12b.

Some Benefits of Billion Cell Models

Figures 13a and 13b compare the predicted water and oil saturations for an area of Ghawar field under a given production scenario at a given time. The image on the left represents the mega-cell simulation model with a 0.25 km areal grid. On the right, the results of the giga-cell simulator with a 0.042 km grid for the same reservoir at the same time are illustrated. The red color represents oil, and the blue color represents water.

Under the given production scenario, the mega-cell simulator shows that water will move much faster, sweeping a larger area, leaving no oil behind.

The giga-cell simulation, however, reveals that there will be unswept zones, which will have oil remaining if this production scenario is to be applied. This example illustrates the clear effect of numerical dispersion for the mega-cell simulation, which is unrealistic. Giga-cell simulation shows less numerical dispersion. Based on the results of the giga-cell simulation, additional oil pockets indicated by the simulator should be produced by in-fill drilling or sidetracking the wells.

Therefore, in this example, giga-cell simulation presents opportunities to recover more hydrocarbons.

Next Stages

Significantly more data will be available through online measurements and continuous monitoring. Voice recognition technologies are becoming smarter at understanding spoken commands from people with different English language accents. Better graphics technology will be available to render multibillion-cell images in real time. CPU technology will be complemented with Graphical Processing Units (GPUs) for the computer intensive aspects of simulation and data analysis that can benefit from parallel computation using hundreds of cores in parallel.

Figure 14 presents a visionary prediction for the growth of a black oil equivalent model size over the years. As shown, present computers can easily deliver teraflops (10**12 FLOPS (Floating Point Operations per Second)). Only large computer centers can deliver petaflops (10**15 FLOPS) today; however, with rapid development of GPUs and other evolving computer technologies, eventually this will become available for smaller systems housed in the office. Again, with the current momentum, exaflop computers are on the horizon. All will impact the size of the simulation models. Saudi Aramco soon will be changing algorithms and rewriting new codes to achieve tera-cell reservoir simulation models with petaflop or exaflop computers.

Summary and Conclusions

Giga-cell reservoir simulation technology has been developed and implemented on the world's largest offshore and onshore oil reservoirs. Many cases have already successfully documented the high impact results that fine grid models yield, increasing the understanding of the Saudi Arabian reservoirs.

Giga-cell simulation technology reveals the crucial details that enable engineers and geoscientists to build, run and analyze highly detailed oil and gas reservoir models with great accuracy, which will help companies recover additional oil and gas. Overall, giga-cell simulation is expected to be beneficial for mankind in its quest to produce more hydrocarbons to sustain the world's economic development.

Acknowledgements

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Ali shares four U.S. patents and is the author of over 40 technical publications. He is the recipient of the 2008 SPE International Reservoir Description and Dynamics Award and the 2010 World Oil Innovative Thinking Award. The project that he leads, GigaPOWERS, received the 2010 ADIPEC Best Technology Award.

Determination of Crude Oil Saturation Pressure Using Linear Genetic Programming

By Abdulrahman A. AlQuraishi, King Abdulaziz City for Science and Technology, Oil and Gas Center.

Saturation pressure is a PVT property predicted either by equations of state or empirical correlations. Both are known for their limited accuracy. In this work, a new model is developed to estimate crude oil saturation pressure using linear genetic programming (GP) technique. A total of 131 crudes covering wide ranges of composition and reservoir temperature and different geographic origins were used to build and test the model. The database used consists of reservoir fluids composition (N_2, CO_2, H_2S, methane to hexane, and heptane plus components), sepecific gravity, and molecular weight of the heptane plus fraction, reservoir temperature, and the experimentally measured saturation pressures. The data were randomized to exclude the effect of crude geographical origin and divided into three data sets (training, validation, and testing). The training and validation data sets were composed of 41 crude oils each, and they were used to build the model. The rest of the data were used to blind test the model developed. The proposed model efficiency was tested against two known equations of state (Soave Redlich Kwong and Peng–Robinson) in addition to Elsharkawy empirical correlation. The testing process indicates the superiority of the proposed model in term of average absolute relative error. The proposed model is much simpler than the emprical correlation predicting saturation pressure as a function of only three input variables, namely the methane mole fraction, molecular weight of the heptane plus component, and the reservoir temperature. In addition, it eliminates the need for splitting and characterizing the heavy fraction necessary for the equation of state models.

Introduction

When crude oil is in contact with gases, the saturation pressure measurement or prediction becomes crucial for reservoir studies (i.e., enhanced oil recovery). Saturation pressure is a PVT property frequently measured experimentally or predicted empirically using PVT correlations if surface or downhole samples are unavailable. PVT correlations are mostly a function of the production gas oil ratio, oil and gas gravity, and reservoir temperature. These correlations are limited in terms of accuracy, and it is restricted to the geographical area for which it is developed. A number of cubic equation of state (EOS) models have been developed to describe the phase behavior of reservoir fluids, and none can be considered to be the most accurate to predict all of the properties of reservoir fluids at all conditions.[1-3] The accuracy of EOS models is limited and depends on the procedure implemented to regress the equation parameters,[3] the characterization and analysis

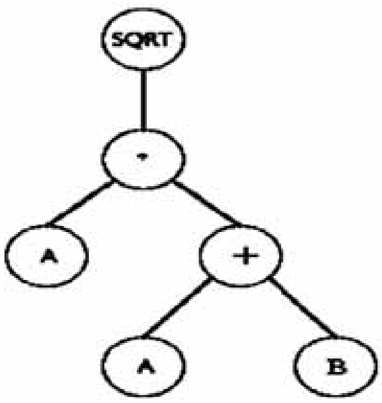

Figure 1. Tree representation of the equation $(A * (A + B))^{1/2}$.

labels	components	model developing data min.	model developing data max.	model testing data min.	model testing data max.
V[0]	N_2	0	1.64	0	1.67
V[1]	CO_2	0	9.11	0	7.1
V[2]	H_2S	0	3.68	0	1.16
V[3]	C_1	5.82	73.36	5.63	74.18
V[4]	C_2	0.84	11.47	1.11	12.45
V[5]	C_3	0.43	11.87	10.9	10.48
V[6]	C_4	1.08	331	0.95	8.4
V[7]	C_5	0.94	365	0.4	6.65
V[8]	C_6	0.99	6.37	0	6.65
V[9]	C_7^+	11.18	83.2	10.72	72.86
V[10]	sp. gr. C_7+	0.743	0.942	0.766	0.92
V[11]	MW C_7+	134	304	146	324
V[12]	T	130	310	128	314
	P_s	313	5065	374	4823

Table 1. Ranges of input parameters used for building and testing the model

```
float DiscipulusCFunction(float v[])
{
 long double f[8];
 long double tmp = 0;
 int cflag = 0;
 f[0]=f[1]=f[2]=f[3]=f[4]=f[5]=f[6]=f[7]=0;

 L0:    f[0]+=v[11];
 L1:    f[0]=sqrt(f[0]);
 L2:    f[0]*=v[12];
 L3:    f[0]-=-386.4619140625f;
 L4:    f[0]=sqrt(f[0]);
 L5:    f[0]*=v[3];
 L6:    f[0]=sqrt(f[0]);
 L7:    f[0]=-f[0];
 L8:    f[0]-=v[3];
 L9:    f[0]+=v[11];
 L10:   f[0]=sqrt(f[0]);
 L11:   f[0]*=v[3];
 L12:   f[0]+=v[11];
 L13:   f[0]=sqrt(f[0]);
 L14:   f[0]*=v[12];
 L15:   f[0]+=v[11];
 L16:   f[0]=sqrt(f[0]);
 L17:   f[0]*=v[3];
 L18:
 if (!_finite(f[0])) f[0]=0;
 return f[0];
}
```

Figure 2. Evolved program in C^{++} language.

Figure 1 Oil and Gas Publication Keyword Distribution

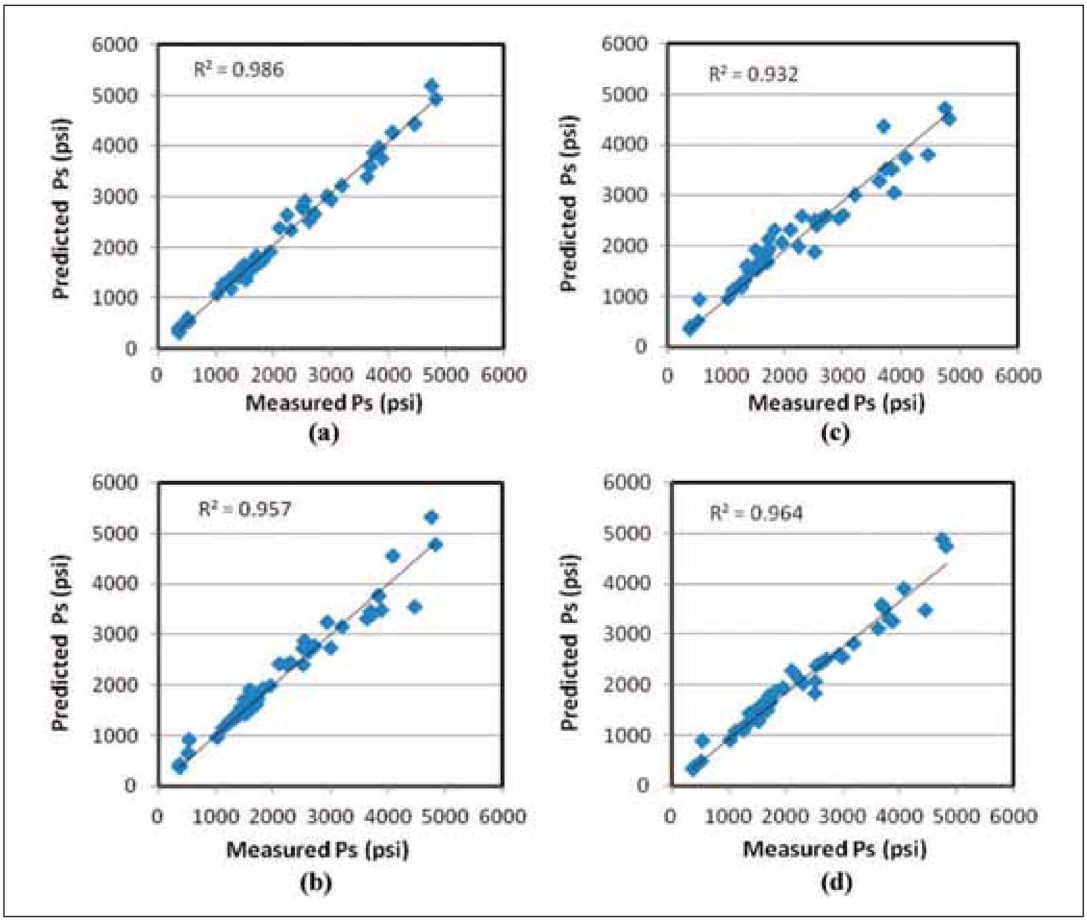

Figure 3. Predicted vs measured saturation pressure using (a) proposed GP model, (b) Elsharkawy empirical correlation, (c) SRK EOS, and (d) PR EOS.

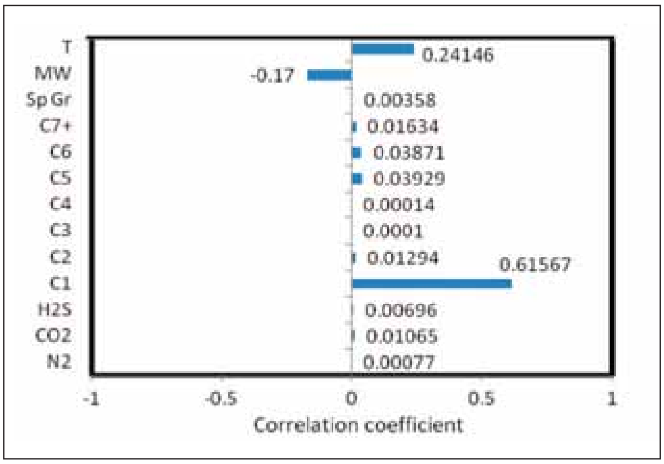

Figure 4. Proposed model sensitivity analysis.

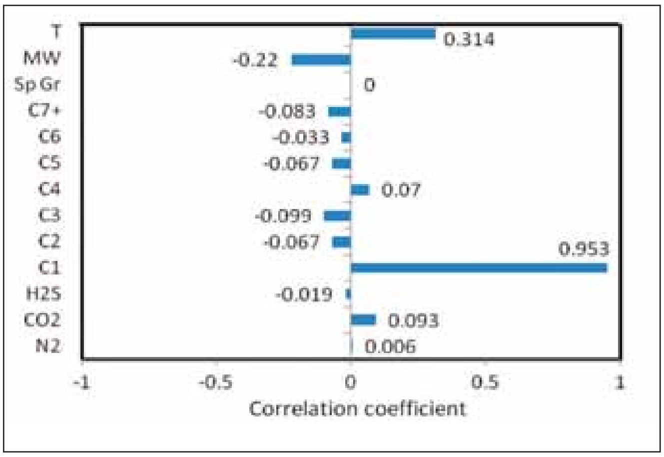

Figure 5. Elsharkawy empirical model sensitivity analysis.

	GP model	Elsharkawy corr.	SRK EOS	PR EOS
AARE	5.813	7.71	9.917	10.139

Table 2. Error analysis of the proposed and investigated saturation pressure models.

of hydrocarbon fractions,[4] and the use of proper binary interaction numbers.[5] EOS models are non-universal and what can be used to describe the properties of one fluid might not be appropriate for other fluids, even from the same basin. Furthermore, EOS models have difficulty converging to the right solution near the critical point.[6]

Soave–Redlich–Kwong (SRK) and Peng–Robinson (PR) cubic equations of state are two of the most widely used and accepted models for reservoir fluid PVT property calculations. They predict saturation pressure with reasonable accracy if the hydrocarbon heptane plus fraction is properly determined,[7] however, the two EOSs calculate the equation parameters differently, leading to unequal estimation of the saturation pressure.

Elsharkawy[8] developed an empirical model to estimate saturation pressure of black oils. Data used in developing the model covers composition, heptane plus properties, reservoir temperature, and saturation pressure measurements for a total of 132 crude oil samples from the Middle East, North Sea, and North America. The correlation was built based on 60 measurements of Middle East crude oils and tested and validated on 75 sample measurements collected from the literature. The accuracy of the model developed was compared to the actual measurements and validated against that predicted by SRK and PR equations of state. The model successfully predicts saturation pressure with high accuracy and eliminates the splitting and characterization of the heavy fraction needed for the EOS models.

Recently, Shokir[9] developed a genetic programming-orthogonal least-squares based model to estimate dew point pressures of gas condensate reservoirs. The model was built and validated using Matlab software on 380 gas condensate samples implementing gas composition, molecular weight of heptane plus fraction, and reservoir temperature as input parameters. The model was successful in estimating dew point pressure with good accuracy, indicating the power of such a technique in generating fairly accurate models.

This study presents a new model for saturation pressure estimation devloped based on linear genetic programming (GP) technique. The model was built and tested using a database of experimentally measured crude compositions, heptane plus properties, reservoir temperature and experimentally measured saturation pressures collected by Elsharkawy.[8] The developed model efficiency is tested against the measured saturation pressures, and the prediction made by Elsharkawy empirical correlation, SRK, and PR EOS models.

Genetic Programming. Genetic algorithms, evolution strategies, and genetic programming belong to the class of probabilistic search procedures known as Evolutionary Algorithms that use computational models of natural evolutionary processes to develop computer-based problem solving systems. Solutions are obtained using operations that simulate the evolution of individual structures through the mechanism of reproductive variation and fitness-based selection. Due to their reported robustness in practical applications, these techniques are gaining popularity and have been used in a wide range of problem domains. The main difference between genetic programming and genetic algorithims is the representation of the solution. Genetic programming creates computer programs as solutions, whereas genetic algorithms create a string of numbers to represent the solution.

Genetic programming (GP) is based on the Darwinian

principle of reproduction and survival of the fittest and analogs of naturally occurring genetic operations, such as crossover and mutation.[9] Genetic programming uses four steps to solve a problem listed as follows[10,11]:

• Generate an initial population (generation 0) of random compositions of the functions and terminals (input) of the problem.
• Execute each program in the population and assign a fitness value.
• Create a new offspring population of computer programs by copying the best programs and creating new ones by mutation and crossover.
• Designation of the best computer program in the generation.

The programs evolved are made of a series of linked nodes taking a number of arguments and giving a single return value. The nodes are either functions (operators) or terminals (variables and constants).[12,15] Functions may include simple ones, such as addition, subtraction, multiplication and division. It may also include other mathematical functions such as trigonometric, Boolean, and conditional operators. However, the terminal set contains the independent variables and parameters used as arguments for the function. The linked nodes are presented as a tree where operators and terminals are the leaves of that tree. Figure 1 is an example representing a simple function $(A/(A + B))^{1/2}$. In this case the function set is (/, +,√) and the terminals set is (A, B).

Results and Discussion

A total of 131 crude oil samples reported by Elsharkawy[8] were used to develop a saturation pressure model using a linear genetic programming technique. The data used cover a wide geographic distribution covering the Middle East, North Sea, and North America. It includes the crude oil composition (N_2, CO_2, H_2S, methane to hexane, and heptane plus components), specific gravity, and molecular weight of the heptane plus fraction, reservoir temperature, and the experimentally measured saturation pressures. The data were randomized to exclude the effect of the crude geographical origin and divided into three sets (training, validation, and testing).

The training and validation data sets, composed of 41 data points each, were used to build the model. The rest of the data (49 data points) were used to blind test the model efficiency. The data used cover a wide range of compositions, temperature, and measured saturation pressures, and Table 1 lists the ranges of the data used in building and testing the model. The GP model was built using commercial genetic programming system (Discipulus) capable of building a computer program out of the data given.

The system was run for 1000 generations with a maximum population size of 500. Several values of crossover and mutation rates were investigated, and the optimum setting found was 50% and 90% for cross-over frequency and mutation frequency, respectively. The function set used was (+, –, *,√), and the terminal set was the 13 input parameters stated earlier, the experimentally measured saturation pressure, in addition to the machine randomly generated constants. The model generation was terminated when the project history showed no improvement, and hence, the evolved program was used to estimate saturation pressure.

Figure 2 presents the best evolved genetic program in C++ code. The f [0], f [1], and so forth are temporary computation variables used in the program evolved. The output of the program is the value of f [0] after the program execution. The variable labels V [0], V [1], and so forth are the names assigned to input data, where V [0] represents the first input data, V [1] represents the second, and so forth (see Table 1). Writing up the equation representing the evolved program, we obtain the following:

$$P_s = D^{1/2} * yC_1 \tag{1}$$

where,

$$D = (C^{1/2} * T) + MWC_7^+$$

where,

$$C = (B^{1/2} * yC_1) + MWC_7^+$$

where,

$$B = (A^{1/2} * yC_1)^{1/2} - yC_1 + MWC_7^+$$

where,

$$A = (MWC_7^{+1/2} * T) - (-386.4619)$$

The model evolved was used to blindly estimate the saturation pressure for the rest of the data (49 data points) not used in the training and validation process, and its efficiency was tested against Elsharkawy, SRK, and PR EOS models. Figure 3 is a cross plot of the four models, indicating the good performance of the GP model devloped. Average absolute relative errors (AARE) indicating the precision of the proposed and tested models are listed in Table 2. The error analysis indicates the superiority of the proposed GP model followed by Elsharkawy empirical model for the data used in this work.

The GP model evolved to be simple and a function of only three independent parameters, namely the mole fraction of methane, molecular weight of heptane plus fraction, and the reservoir temperature,indicating the high impact of these input variables. Figure 4 is the tornado plot indicating the impact of the input parameters on the proposed model. This was conducted using Montecarlo simulation software (@ risk) and for comparison purposes, sensitivity analysis for the Elsharkawy empirical model was also conducted to investigate the impact of the independent parameters on this model. Figure 5 is the tornado plot, indicating the high impact of methane mole fraction, temperature, and heptane plus fraction apparent molecular weight compared to the rest of the independent parameters used in his model. This agrees well with the proposed GP model, which was evolved to be a function of only these three independent parameters. The model proposed eliminates the need for splitting and characterizing the heavy fraction, indicating its simplicity over the equations of state models.

It is worth noting that the proposed GP model utilizes crude data from different origins for training, validation, and testing compared to the Elsharkawy model, which was built based on data of one geographical location (Middle East) and tested on data from different geographic locations (North America and North Sea). Therefore, the model can be considered to be more representative of the geographic origins in both the training and testing procedures.

Conclusions

A model based on a linear genetic programing approach has been developed to estimate crude oil saturation pressures. Input variables used consist of crude composition (C_1 to C_6), heptane plus fraction, heptane plus molecular weight and specific gravity, and the reservoir temperature for 131 crude oils representing wide geographic distribution. The validity of the model was tested against Elasharkawy empirical correlation, and SRK and PR equations of state, and the following conclusions are drawn:

- The proposed GP model shows good performance in terms of accuracy with the lowest AARE followed by Elsharkawy empirical model.

- In terms of simplicity, the model is a function of only three input parameters, namely, the methane mole fraction, heptane plus molecular weight, and the reservoir temperature, compared to the thirteen input parameters needed for the Elsharkawy model and the 12 pseudo components split to describe the plus fractions for the equations of state calculations.

- The GP model sensitivity to the independent variables reasonably matched that of Elsharkawy, indicating the high impact of the three input parameters implemented by the GP model in saturation pressure prediction.

Nomenclature

P_s = saturation pressure, Psi
yC_1 = methane mole fraction
T = temperature, °F
MW C_7+ = heptane plus molecular weight
AARE = average absolute relative error
sp. gr. C_7+ = heptane plus specific gravity

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Velocity Imaging of Near-Surface Structures by Diving-Wave Tomography, Diving-Wave Penetration Correction and Conventional Refraction Analyses

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In this paper, seismic refraction data obtained along a single profile was used to construct a velocity image and to build up a velocity model beneath it by applying different approaches. The simplest one is the conventional refraction analysis or layer refraction which assumes an average constant velocity value for each layer. The second approach is the diving-wave tomography or refraction tomography that has been applied for velocity imaging along the same profile assuming a linear continuously increase of velocity with depth. The third algorithm is the application of the diving-wave penetration correction and construction of a velocity image for the constant velocity soil layer and the vertical velocity gradient bedrock. A comparison between the results of these three approaches has been carried out to show the velocity concurrence of their images.

Velocity-depth model curves have been established to reflect the linear increase of the velocity with depth. A rapid velocity increase with depth within the shallower part of the vertical velocity gradient limestone bedrock followed by a smaller velocity gradient at greater depths can be noticed. Finally, seismic parameters have been calculated for rock material quality estimation of the vertical velocity gradient bedrock. This conclusion confirms the existence of an intensively or completely weathered limestone of the second layer as it was indicated by the drilling results.

Introduction

Three different techniques have been applied to construct a seismic velocity imaging along a single profile at King Abdulaziz City for Science and Technology (KACST), Riyadh, KSA. Conventional refraction analysis or layer refraction, diving-wave tomography, also known as refraction tomography or turning-ray tomography and diving-wave penetration correction approaches have been applied for velocity imaging. This study aims at the estimation of the near-surface geology for civil engineering purposes. A comparison between the velocity imaging constructed from these three techniques was also done to find out the degree of matching between them. Exploratory borings for determination of the soil profile layer thicknesses and lithological description were used supporting seismic data analysis.

Exploratory Borings

The results of the exploratory borings (Soil & Foundation Co. Ltd., 2007) along the interpreted profile were used to support the seismic data analysis. The estimated layer thicknesses and lithological description in the study area are the following: (1) a first layer composed of brown, dense, dry silty sand with gravel with a thickness range of 1.5-4.8 m, (2) a second layer composed mainly of completely weathered limestone with an average thickness of 6.5 m, and (3) the third layer is formed of moderately weathered limestone.

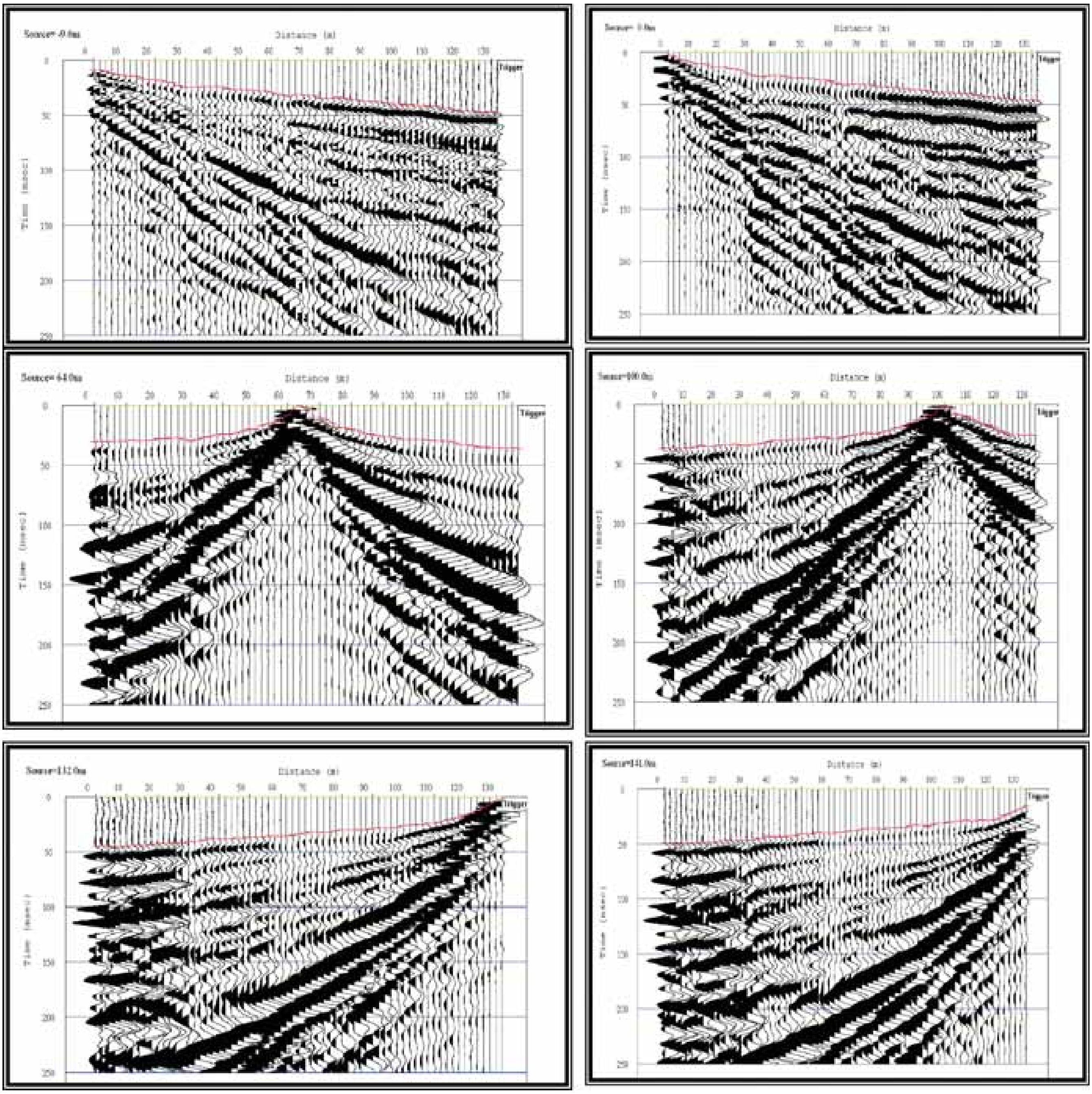

Fig. 1: Examples of shot records for conventional refraction analysis.

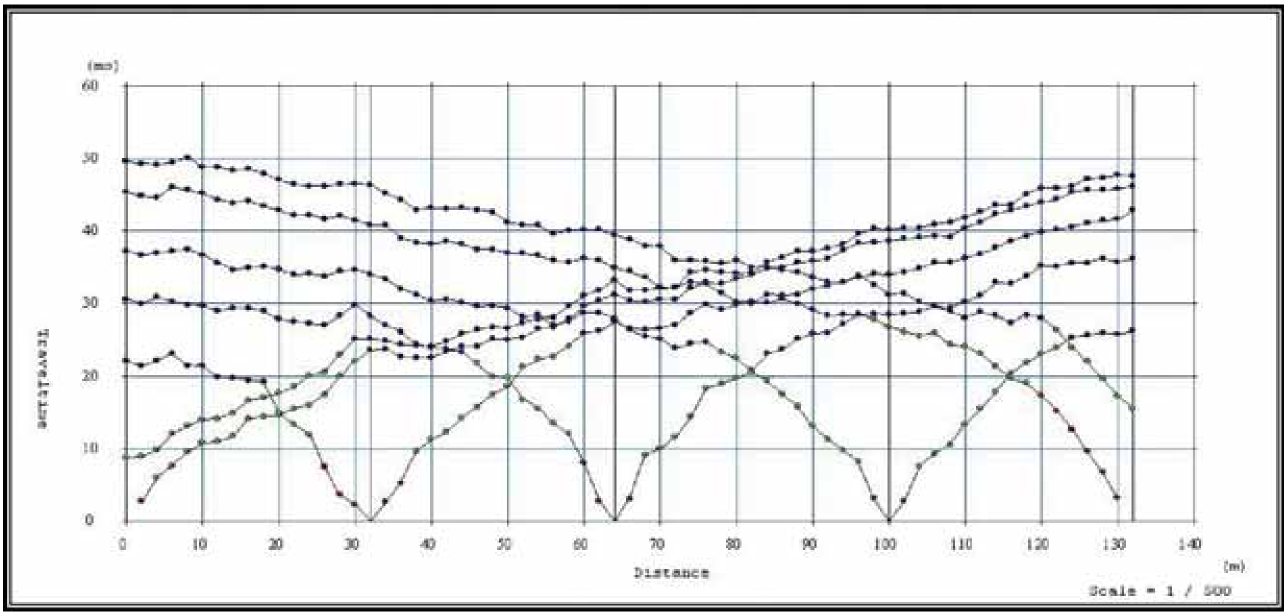

Fig. 2: Traveltime-distance curves along the studied profile.

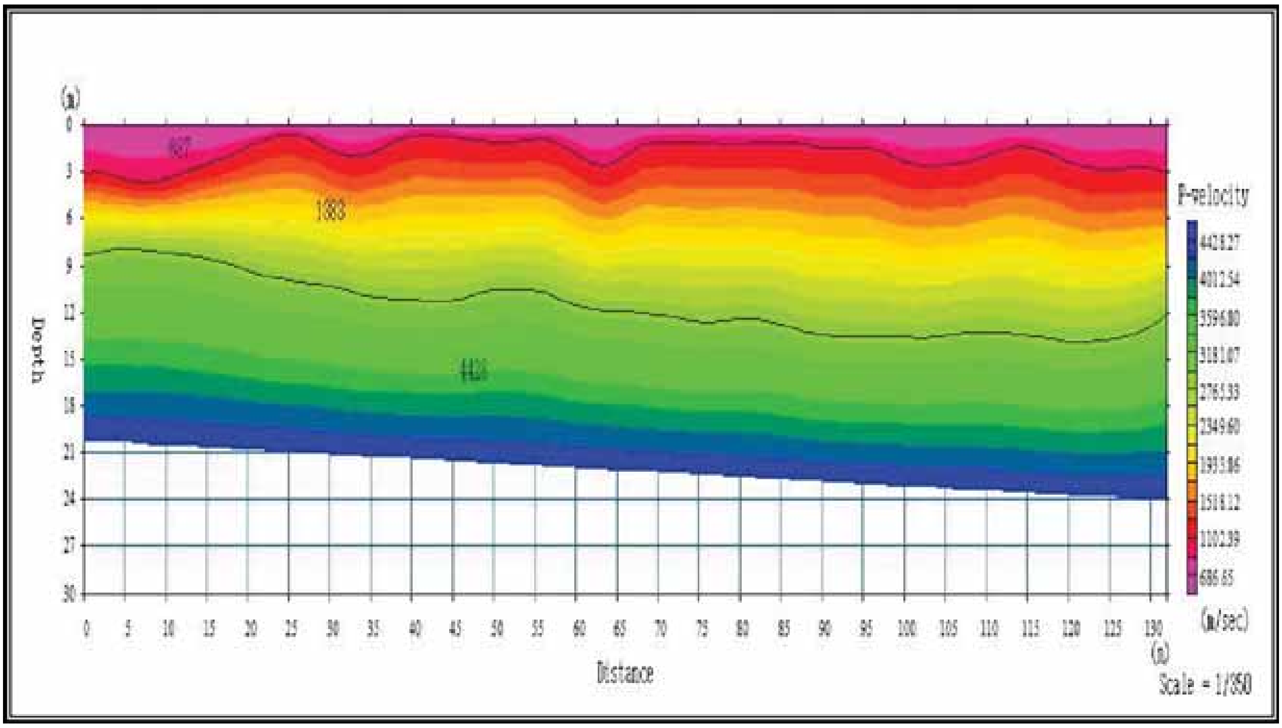

Fig. 3: Velocity image constructed from conventional refraction analysis.

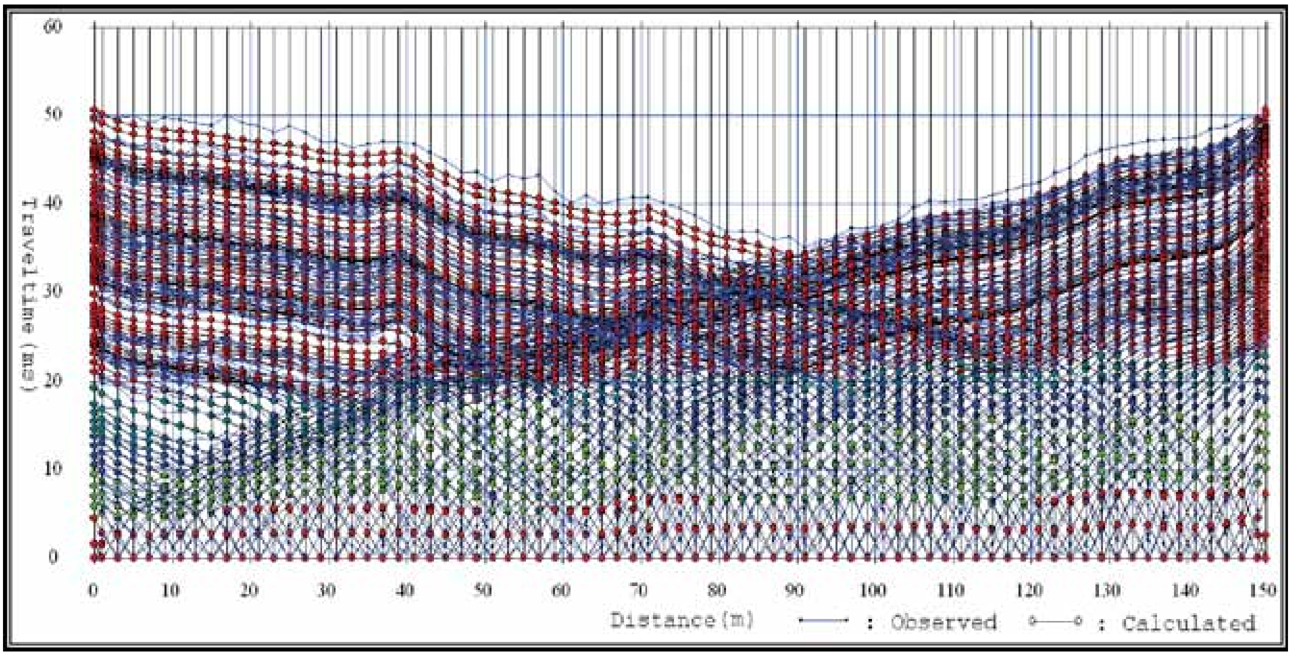

Fig. 4: Traveltime-distance curves for diving-wave tomography.

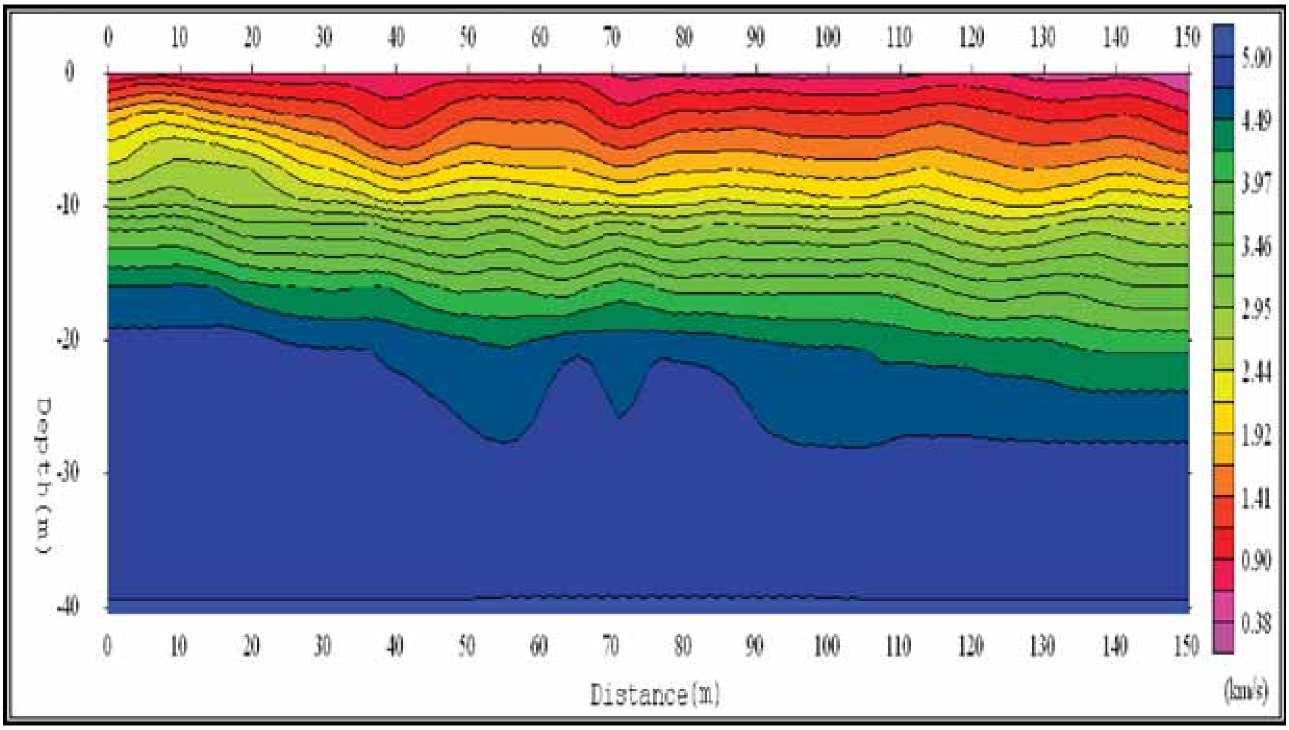

Fig. 5: Velocity image constructed from diving-wave tomography analysis.

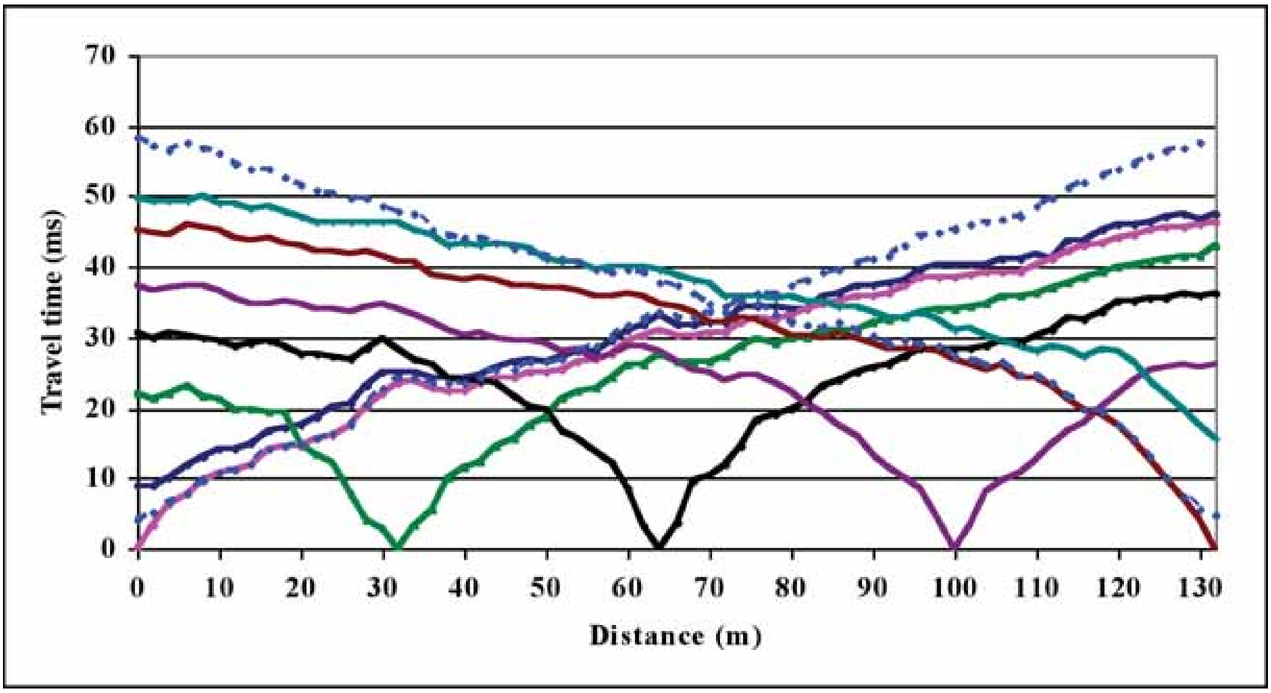

Fig. 6: Traveltime curves of diving-waves (solid lines), corrected times of head waves (dashed lines).

Seismic Data Analysis

The different techniques used in this study are the following:

(1) Conventional Refraction Analysis:

In the conventional refraction analysis the shallower part of the geological section is described as layers wherein velocities change very smoothly but very sharply at the boundaries between the layers. In-line spread layout was conducted along the interpreted profile for generation of compressional seismic waves. The total interpreted seismic profile length is 132 m with 2 m geophone interval. Seven shot points were located at the following distances: -9, 0, 32, 64, 100, 132 and 141 m constituting two end-on shots (0 and 132 m), two offset shots (-9 and 141 m) and three split-spread shots (32, 64 and 100 m). A hydraulic weight drop was used as a source of seismic energy vertically hitting a steel striker plate. The generated seismic energy was measured by a 14 Hz vertical geophone and recorded by a multi-channel signal enhancement Seismograph of Geometrics Inc. (Geode and Strata Visor NZ Model). Some selected shot records (seismograms) are shown in Fig. 1.

An advanced SeisImager Software Package (Geometrics Inc., 2005) has been used for seismic data processing sequence. Travel time-distance curves are established along the acquired profile (Fig. 2). First-break picking and layer assignment were done for each segment on the travel time-distance curves, and finally, the velocity-depth image along this profile has been constructed showing average velocity values 687, 1383 and 4428 m/s for the first, second and third layers, respectively as shown in Fig. 3 with average thicknesses 2.5 and 7.5 m for both of the first and second layers, respectively.

(2) Diving-Wave Tomography:

Several literatures explained diving-wave tomography, also known as refraction travel time tomography or turning-ray tomography which uses first-arrival travel

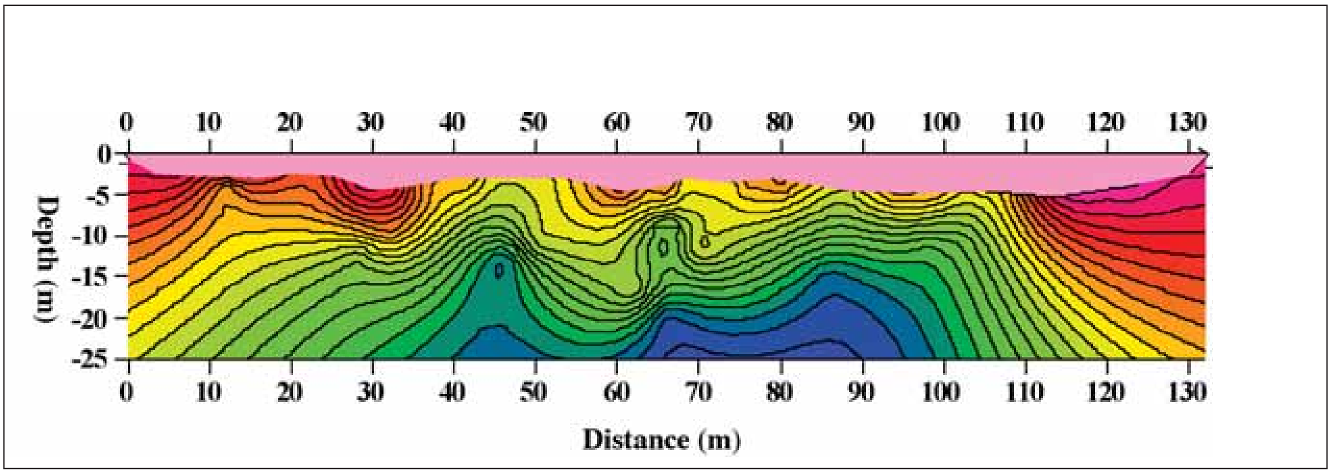

Fig. 7: Velocity image constructed from diving-wave penetration correction approach.

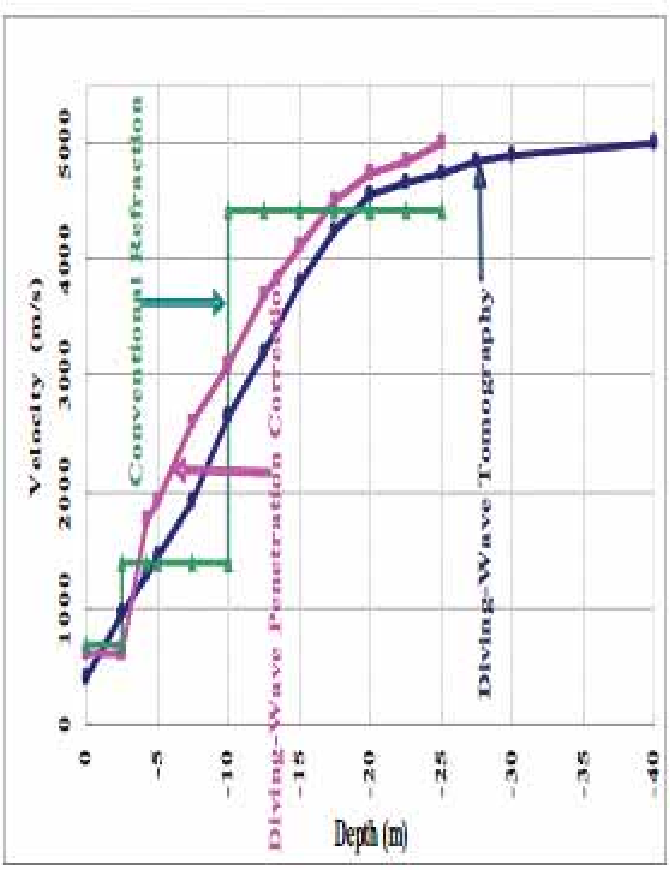

Fig. 8: Velocity models constructed from the three different approaches.

time as input data (e.g. Zhu and McMechan, 1989; Zhu, et al. 1992; Stefani, 1995; Zhu, et al. 1998; Osypov, 1999; Kanli, et al 2000, 2001; Zhu, et al. 2001; Zhu, 2002; Speece, et al. 2003; Kanli, 2008 & 2009; Kanli, et al 2008; Teimoornegad and Poroohan, 2007 & 2008; Miller, et al. 2005).

Seismic tomography is usually formulated as an inverse problem. It is a seismic imaging technique for estimating the compressional wave velocity. Several methods have been developed for this purpose, e.g. refraction travel time tomography, finite-frequency travel time tomography, reflection travel time tomography and waveform tomography. In refraction travel time tomography, the observed data are the first-arrival travel times t and model parameters are the slowness S. The forward problem can be formulated as $t = LS$, where L is the forward operator which, in this case, is the raypath matrix. The solution involves minimization of the difference between the observed travel times and those predicted (calculated) by ray tracing through an initial model. Zhu (2002) explained five steps for that iterative solution: (1) picking of first-arrivals, (2) ray tracing through an initial estimate of the velocity model, (3) segmenting ray paths into the portion contained in each cell of the velocity model, (4) computing the differences between the observed and predicted travel times for each ray, and (5) iteratively back projecting the time differences to produce velocity-model updates. Velocity updates are performed by a simultaneous iterative reconstruction technique (SIRT).

In the present study, seismic tomography profile was conducted along the same location of the conventional profile. Geophone interval was also 2 m and the shot points were moved along the profile and shot at each geophone location, i.e. shot interval = geophone interval = 2 m. The total number of shots was 77 shots, the total number of geophones was 75 and the number of stacks was 3 for each shot. The travel time-distance curves along the interpreted profile produced from each shot are shown in Fig. 4.

SeisImager Software Package was also used for processing steps of the seismic tomography travel time-distance curves. The final result is a velocity image along the interpreted profile (Fig. 5). The velocity image shows the following features: deeper depth values till 40 m, color scale of the velocity image range from 380 m/s to 5000 m/s, and a better image enhancement than conventional refraction analysis. This tomography velocity image or tomogram is very useful during the construction of the high-rise or tall-buildings and establishment of the modern seismic design building codes.

(3) Diving-Wave Penetration Correction Algorithm:
In this paper, we have an ideal case study of constant soil layer velocity overlying bedrock with a continuous velocity increase with depth. Small velocity values around 1500 m/s are found at the top surface of this limestone bedrock due to the effect of strong weathering processes which decrease with depth. As the weathering and fracturing processes gradually decrease with depth, the seismic velocity increases gradually and continuously as well. This medium can be considered as a vertical velocity gradient medium and the velocity-depth distribution V=V (z) can be expressed by linear, parabolic, exponential or any other velocity function. Seismic waves propagate in this medium according to Snell's law along curved trajectories, returning back to the ground surface. This kind of waves are called diving waves and they can be demonstrated by the convergence of their overtaking travel time-distance curves. The depth within this medium can be determined according to Wiechert-Herglotz-Bateman equation (Slichter, 1932) by using only single travel time-distance curve. However, in our study we used each pair of reversed travel time-distance curves for depth determination by an equation modified for linear velocity function.

There have been many theoretical studies disclosed that seismic wave velocities within layers are not constant (see, Rubey, 1927; Terzaghi, 1940; Faust 1953; Gassman, 1951; Jankowsky, 1970, Gurvich, 1972; Greenhalgh, 1976; Greenhalgh et al., 1980; Greenhalgh and King, 1981; Skopec, 1981 & 1989; Skopec and El-Werr, 1996; El-Werr and Skopec, 1996; and El-Werr, 1999a & 1999b).

All interpretational methods are designed only for using head waves. However, in our case the existence of diving-wave is very remarkable from the convergence of their overtaking travel time-distance curves (Fig. 6). For this reason, diving-wave travel times should be transformed into travel times of head waves by introducing a diving-wave penetration correction. If we do not introduce this correction, the results will bear errors in depth and velocity determinations at the surface of the bedrock. The velocity image constructed from this approach (Fig. 7) shows a constant soil layer velocity (600 m/s) of silty sand with a thickness range of 1.6-4.5 m overlying a completely weathered limestone with a gradual increase of velocity with depth. The velocity at the top surface of the bedrock is about 1500 m/s for the completely weathered limestone while it attains more than 5000 m/s for intact massive limestone at depth of 25 m.

(4)Velocity Model Construction:
New buildings are planned to be constructed in the near-future of the study area. In addition to the aforementioned velocity imaging, velocity models represented by velocity at each depth will help to a great extent during construction of these buildings. Three velocity models are established along the studied profile. The first velocity model (Fig. 8) is established from the results of the conventional refraction analysis which assumes almost constant average velocity values 687, 1383 and 4428 m/s for the studied three layers at depths about 2.5 and 10 m. The second velocity model is established from the diving-wave tomography (Fig. 8). It shows small velocity value (380 m/s) for the first silty sand layer, then an intensive weathered limestone bedrock with a velocity at its surface around 1000 m/s which increases rapidly with a large vertical velocity gradient till it reaches 4250 m/s at depth of about 17.5 m, and finally the velocity increases slightly to 5000 m/s at depth 40 m. The third model is constructed from the data analysis of the diving-wave penetration correction approach (Fig. 8). It shows constant first layer velocity overlying completely weathered bedrock with also rapid velocity increase with depth followed by intact limestone with slight velocity gradient.

(5) Rock Quality Estimation from Seismic Parameters:

Seismic parameters in the form of velocity increment $\Delta V(\Delta Z)$, weighted velocity gradient $V_G = V\Delta V/\Delta Z$ and velocity gradient $K = (V(Z) - V_O))/V_O Z$, where V is the mean velocity of two $V(Z)$ values with difference ΔV at two successive depths within a depth interval ΔZ, V_O is the velocity at the top surface of the bedrock, have been calculated at x-co-ordinate 30 m for the second and third approaches. These values are found to be more close to each other from these two approaches and they are equal to 236 S^{-1}, 573 x10^3 mS^{-2} and 0.077 m^{-1}. This confirms that this limestone bedrock has a good material quality with large seismic parameters which is suitable for building as a foundation layer.

Conclusions

Conventional refraction analysis, diving-wave tomography and diving-wave penetration correction have been carried out along a single profile to construct a velocity image of the constant soil layer velocity and the vertical velocity gradient bedrock. A comparison between the results of these three approaches has been done to test them together with each other and to indicate the reliability of their results. A velocity concurrence between the three obtained images has been noticed.

Also, velocity model curves have been established to reflect the amount of the linear increase of the velocity with depth. A rapid velocity increase with depth within the shallower part of the vertical velocity gradient limestone bedrock followed by a slight velocity gradient at greater depths has also been observed. For estimation of the rock material quality, seismic parameters have been calculated for the vertical velocity gradient bedrock. It was determined that seismic parameters are large enough to document a bedrock with good material quality in spite of a high degree of weathering. It can be concluded that a good correlation is found between the results of the applied three approaches and these results were supported by exploratory boreholes. This kind of diving-wave analysis for velocity imaging is very useful for tall-buildings construction and establishment of the modern seismic design building codes.

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Water Control and Relative Permeability Modifiers – Laboratory Screening for Improved Results in a Middle East Context

By Clive Cornwall, Corex (UK) Ltd.

Introduction

Relative Permeability Modifiers (RPMs), after a period of extreme user scepticism, are once again being considered as an effective method of controlling unwanted water production in both oil and gas reservoirs. The inclusion of RPMs in the conformance engineer's portfolio of possible remedial solutions is being driven, in part, by the introduction of new and improved products by a number of major chemical suppliers. These companies are responding to the ever growing number of maturing fields, in all hydrocarbon provinces including the Middle East, which are plagued by excessive water production and to the demands of clients to extend viable hydrocarbon output beyond current predictions.

The RPM's original fall from grace was driven by extravagant claims for universal applicability, in essentially all lithologies. The point has been made that if the majority of RPM treatments had met with measurable and general success, their deployment would not have declined quite so dramatically. It may be argued that this pattern of initial misplaced optimism, followed by a broad rejection of the products and the techniques, could ensnare the present range of products, thereby dissipating their believed potential.

There is a significant body of research concerned with the theoretical mechanisms that enable RPMs to suppress water flow while permitting hydrocarbons to move without undue interference. A common thread running through this work is a realisation that the success or failure of an RPM treatment is dependent on the unique combination of factors found in the target well and reservoir. Of the myriad of contributing elements to be considered, wettability is of particular importance, as it directly determines the level of polymer attachment and subsequent retention.

A realisation of the importance of wettability to the success of an RPM treatment would surely lead to a requirement for the determination of the wetting preference of the formation to be a key component of the pre-injection planning. Unfortunately in the majority of cases this measurement step is missing from the sequence. In fact in correspondence with one of the major suppliers the point was made that a formation is presumed to be water-wet unless advised otherwise by the client. Where the wetting preference is predicted not to be water-wet, the standard advice is to "clean" the formation, to achieve the desired water-wet preference. Such assumptions are not routinely checked to ensure the formation can be prepared to maximise polymer adsorption and to minimize displacement during subsequent production.

This paper seeks to make the case for an integrated core analysis and petrographic screening study, in conjunction with one or more RPM formulations, to determine which product is most suited to the prevailing conditions. It also affords an opportunity to modify a particular RPM formulation to maximise its potential and where a clean-up chemical is to be used, to ensure it will have the desired effect.

Background

The wide gamut of test formats available to the core analyst is many and varied, and provides a powerful device in defining the original condition of the rock material and the saturating fluids. The inclusion of petrographic examination, in the form of thin section analysis, SEM and XRD enhances this original assessment process. Thereafter, the ability to perform testing following on from treatment with both conditioning and RPM chemicals generates comparative data sets for the determination of “before and after” trend patterns, thus suggesting the effectiveness of each selected product.

The Relative Permeability Modifiers that would benefit from an integrated package of core analysis screening are the non-sealing, water soluble polymers, whose purpose is to reduce the flow of water into the wellbore, without unduly suppressing the production of the oil phase. The manifestation of the alteration in the flow patterns is found in the effective water and oil permeabilities, and in the fluid saturation profiles. Such parameters can be measured under reservoir conditions of pressure and temperature, with crude oil and simulated formation brine, as part of the core analysis screening.

The effective oil and water permeabilities, on a before and after treatment basis, are translated into (Residual) Resistance Factors to water and oil, which are taken as a measure of the success of the RPM in controlling water production while maintaining the passage of oil.

The (Residual) Resistance Factor values available in the literature supplied by the chemical companies are encouraging, although the use of standard sandstones, which are naturally water wet, reduces their applicability to specific well conditions. The impact of wettability is discussed later in the paper and its importance is demonstrated in terms of the relevance to polymer attachment and the movement of fluids within the pore system.

Candidate Test Formats

A typical screening exercise would draw upon the following test formats to define the important petrophysical and petrographic characteristics that have a potential bearing on the success of the RPM treatment.

- Combined Amott/USBM Wettability, together with sourcing of suitable core material and its possible restoration.
- Effective Water Permeability at Residual Oil Saturation and Effective Oil Permeability at Irreducible Water Saturation for (Residual) Resistance Factor to Water and Oil
- Specific Gas Permeability, Pore Volume and Porosity, with Dean Stark Extraction
- Mercury Injection Capillary Pressure for pore throat size distribution
- Petrographic Analysis - Thin Section, SEM and XRD

Each of these formats is discussed in the subsequent subsections, culminating in a generic preparation and measurement sequence, presented in Figure 1.

Wettability – Comments and Determination

It is generally accepted that the water soluble RPM products being offered by the major chemical suppliers require the rock matrix to be preferentially water wet, to ensure robust adsorption and attachment, and prolonged adhesion. If all reservoirs had an affinity to water in the presence of oil, the need for screening would be removed. The assumption that all reservoirs are very strongly water-wet has formed the basis of a significant body of reservoir engineering practice for some considerable time. The rationale for this assumption being that water originally occupied the reservoir trap and that as oil swept the formation the water phase would be retained by capillary forces in the finer pore spaces and as films on grain surfaces overlain by oil. However, there is a growing movement away from this viewpoint, based on published evidence into the effects of crude oil on wetting behaviour, towards an acceptance that most reservoirs are at wettability conditions other than very strongly water wet. Extensive testing has shown

Mineral	Percent
Quartz	83
Feldspar	5
Clays	9
Other Minerals	3

Table 1 – Typical Mineralogical Content of Berea Sandstone

that reservoir wettability can cover a broad spectrum of wetting conditions from very strongly water wet to very strongly oil wet. Within this range complex mixed wettability conditions given by combinations of preferentially water wet and oil wet surfaces have been identified. Mixed wettability in the reservoir often results from surface-active molecules in the crude oil adsorbing onto grains over time.

The point has been made that rock properties such as relative permeability and capillary pressure, depend on the distribution of water and oil in the pore space. In order for laboratory measurements to be representative, it is necessary for the pore level distribution of the fluids and the wettability to be the same in the laboratory as in the reservoir. Unfortunately much, if not all, of the laboratory based proving of the RPM chemicals has been conducted on standard sandstone plugs, such as Berea (see table 1). These sandstone plugs are cleaned with solvents prior to saturation with brine and oil, which creates a uniform wetting preference. Anderson in his review of the technical literature with respect to rock-oil-brine interactions and wettability observes that when all surface contaminants are carefully removed, most minerals, including quartz, carbonates and sulphates are strongly water-wet.

The requirement for a water-wet surface casts doubt on the use of RPMs in carbonate reservoirs. Published studies have concluded that carbonate reservoirs are typically more oil-wet than sandstone. Such differences are linked to different adsorption characteristics of silica and carbonate surfaces, in terms of simple polar and crude oil compounds. In recent field investigations performed on carbonate cores from the Middle East, the trend was for a general intermediate to slightly oil wet preference in the oil column. However, the ability to screen carbonate core provides an opportunity to test whether the presumption is valid or whether a modification of the formulation would be beneficial for RPM adsorption.

The preferred method for measuring the wettability of the core samples, whether fresh, cleaned or restored state is the Combined Amott/USBM method. The combination of the two techniques ensures all possible wetting preferences can be determined, including mixed and non uniform wettability.

The generation of the wettability indices would be undertaken on a specific suite of plugs. For the determination of the inherent wetting preference of the reservoir, the plugs would be in either a fresh or restored condition (see below). When it is necessary to assess the impact of the cleaning chemical, the plugs would be flushed with the selected chemical prior to the wettability testing.

The Condition of the Test Core

The screening process is dependent on the securing of representative core material, in terms of its petrophysical and petrographical properties.

The preferred option is for the cutting and trimming of plugs at wellsite at selected depths across the reservoir section. Ideally the core should be taken with a low invasion coring system, to minimise mud filtrate invasion. It has been shown that oil based mud filtrate will alter the wettability of the reservoir rock. Emulsifiers and surfactants included in these fluids, even at low concentrations, have been shown to be responsible for a change in wettability. Water base mud will arti-

Formulation A

Permeability Flow Rate	(R)RF Water	(R)RF Oil
1 ml/min	25.3	2.1

Based on a restored state sandstone plug with a specific gas permeability of 125 mD. Plug flushed with treatment fluid prior to injection of RPM and shut-in for 12 hours.

Formulation B

Permeability Flow Rate	(R)RF Water	(R)RF Oil
1 ml/min	39.2	1.8

Based on a restored state sandstone plug with a specific gas permeability of 210 mD. Plug flushed with treatment fluid prior to injection of RPM and shut-in for 12 hours.

Table 2 Example – (Residual) Resistance Factors for Water and Oil Generated from Two RPM Formulations

ficially enhance the residual water saturation present in the pore space and may contain wettability altering surfactants. The plugs, taken from the "undisturbed" centre of the core would be preserved in a closed environment pending analysis.

If it is necessary to use archived core, which is either inappropriately preserved or has suffered long term atmospheric exposure, it is advisable to restore the core to re-establish the representative wettability and saturation profile. In the laboratory the reservoir wettability of cores can usually be restored by duplicating the process that established the wettability in the reservoir (31).

• Establish a water-wet state by solvent cleaning. A clean mineral surface is indicated by a water-wet condition since clean silica and calcite are strongly water wet. This is a typical sequence but there will be exceptions, for example when fatty acid emulsifiers are added to an oil base mud (32). In such cases the cleaning sequence must be adapted to the specific case.

• Establish saturations representative of the reservoir, or more precisely, a representative pore-level distribution of water and oil.

• Ageing in the presence of a high saturation of crude oil at reservoir temperature.

The use of core plugs that have been vigorously cleaned with solvents, such as xylene and methanol, without subsequent ageing in crude oil, is not advisable as it will skew the following Permeability Resistance Factors toward an overly optimistic position. It will also prevent an unbiased assessment of any clean-up chemicals that may be recommended by the RPM suppliers.

Determination of the (Residual) Resistance Factors for Water and Oil from Effective Permeabilities to Water and Oil

The plugs, whether in a fresh or restored condition, will be at irreducible water saturation with the remaining pore space filled with oil. They are mounted in individual hydrostatic core holders, a representative effective reservoir overburden pressure is applied and the assembly placed in an oven set at the reservoir temperature (see Figure 2). Following a period of stabilisation the following conditioning and measurement sequence is undertaken:

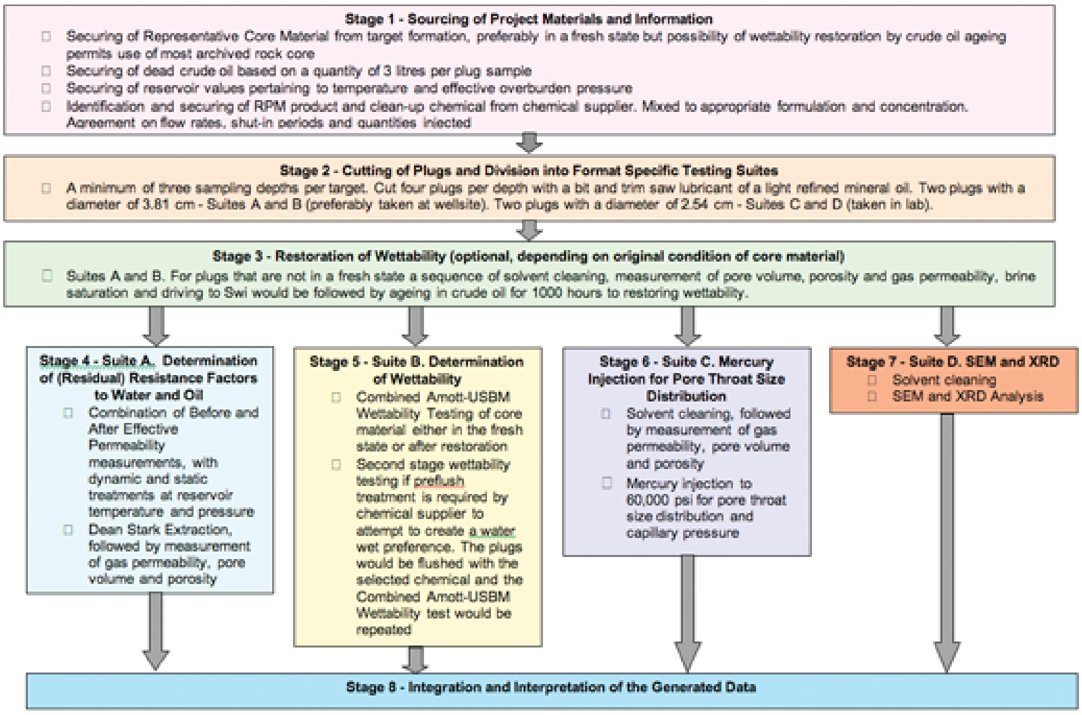

Figure 1 - Flow Diagram for Programme of RPM Screening

- Effective oil permeability at irreducible water saturation (Formation to Wellbore)
- Flood to residual oil saturation (Formation to Wellbore)
- Effective water permeability at residual oil saturation (Formation to Wellbore)
- Flushing with cleaning chemical (if required by chemical supplier and operator) (Wellbore to Formation)
- RPM treatment (Wellbore to Formation)
- Flood to residual water saturation (Formation to Wellbore)
- Effective Oil Permeability (Formation to Wellbore)
- Flood to residual oil saturation (Formation to Wellbore)
- Effective water permeability at residual oil saturation (Formation to Wellbore)

This generic sequence can be modified to reflect the specific requirement of the chemical supplier, in conjunction with the operator, in terms of flow rates, shut-in periods and quantities injected. The selection of the flow rates is of particular importance to minimize polymer stripping during subsequent formation to wellbore production. The flushing cycles can also be altered should there be a need for over-flushing or focusing on a single phase rather than both water and oil. Additional analysis may also be included to monitor the amount of RPM polymer present in the effluent to chart the rate of displacement associated with prolonged flushing after treatment.

The pairs of effective water and oil permeability values provide a measure of the efficiency of the RPM treatment in terms of (Residual) Resistance Factors (see Table 2):

(Residual) Resistance Factor (to water and oil) = Permeability (mD) Before Treatment / Permeability (mD) After Treatment

The end point saturation values of irreducible water and residual oil may also be taken as indicators of the impact of the cleaning chemical and RPM in terms of water retention and the production of the oil phase.

Specific Gas Permeability, Pore Volume and Porosity, with Dean Stark Extraction

On completion of the fresh or restored state testing,

Principal Components:

Large capacity oven
Fluid delivery system comprising Constant Flow Rate pumps, 0.0001 to 45ml per min, 10,000 psi mwp and a pair of floating pistons housed within the oven
Integrated data acquisition and pressure (absolute and differential) detection system
Hydrostatic core holder, 10,000 psi mwp
Overburden pressure system, 10,000 psi mwp

Fig 2. Reservoir Conditions Test Rig for rpm Screening.

the end point water and oil saturations are fixed by Dean Stark extraction. The base parameters of gas permeability, pore volume and porosity of the clean and dry plugs are measured under ambient conditions. The end point fluid saturations are expressed as percentages of the measured pore volume.

Mercury Injection Capillary Pressure and Petrographic Analysis

To understand the interplay between the RPM and rock matrix, an in-depth characterisation of a representative range of samples from the available core material is recommended.

Mercury Injection to 60,000 psi will fully quantify the pore throat size distribution, which is a key factor in the control of flow in general, and the subsequent suppression of water movement within the pore system.

Thin Section, SEM and XRD analysis assists in the interpretation of the data generated by the screening process. For example, core material containing coal can be naturally neutrally wet, as suggested by an inability to achieve a strongly water wet preference during prolonged solvent cleaning. Another example may be found in the oil wetness of the North Burbank unit, which is caused by a coating of chamosite clay on the grain surfaces. Clays in general can adsorb asphaltenes and resins that can make the clays distinctly oil wet. Once attachment has occurred, as found with kaolinite and montmorillonite, it is difficult to remove. The presence of carbonate cements may also be detected through petrographic examination and will add an appreciation of the contributing elements in a sample's wetting preference.

Conclusions

To maximise the benefits of RPM treatments, whether directly into the matrix or associated with fracturing, an understanding of the properties of the target formation is vital. This knowledge base will also assist in selecting the pre-treatment processes and solutions that are applied to create a water wet preference for polymer attachment.

Screening of the representative reservoir rock plugs under simulated reservoir conditions diminishes uncertainty. It also removes the current reliance on standard sandstones or cleaned reservoir core, with its encouragingly water wet preference, to predict the successful suppression of unwanted excessive water production.

Analysis of Long-Term Production Performance in Acid Fractured Carbonate Wells

By Dr. Zillur Rahim, Mahbub S. Ahmed and Adnan A. Al-Kanaan, Saudi Aramco.

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Abstract

Gas condensate wells within the Khuff carbonate formation in Saudi Arabia are typically acid fracture stimulated following drilling. Pressure transient tests conducted after stimulation indicate excellent fracture conductivity and reasonable lengths. After tie-in, the wells experience some early production change, which stabilizes after 3 to 5 months. The producing bottom-hole pressure (BHP) of many such wells also falls near or below the dew point pressure during this period.

This article identifies some reasons for this production and pressure behavior. Possible causes of the early rate change followed by stabilization, which include near well liquid drop-out, fracture conductivity deterioration with increased effective in-situ stresses, reservoir permeability loss also due to increased effective stresses and pressure drop, and non-Darcy flow, were investigated. This article presents the changing total skin with time and allocates it to each of the potential damage mechanisms. This was accomplished using a full geomechanics and reservoir simulation model, which treats multiphase flow effects and stress-dependent matrix permeability as well as fracture conductivity. By doing so, the production behavior was matched and the main controlling factors were identified.

This article introduces a generalized skin factor equation combining all major variables controlling production, separates individual terms with respect to well rates and identifies the main mechanism impacting production behavior.

Introduction

An analysis of the long-term production behavior of acid fracture stimulated gas condensate wells was conducted and included the following primary functions: (1) Review and model the production performance of six wells in the gas carbonate reservoir in Ghawar, and (2) Determine the contributions of various reservoir and fracture parameters on the productivity behavior.

The primary goal of modeling the historical production behavior of the six vertical wells (SA-1 through SA-6) was to identify the mechanisms impacting productivity change with time. After the wells were drilled and completed, an acid fracture treatment was performed on each well and the wells were cleaned up. After clean-up but before tie-in, multirate flow and buildup tests were performed on the wells. A two-year production period was investigated and used for history match purposes.

The production behavior response of all wells exhibited high initial productivity index (PI) prior to rate stabilization. The changes of PI over time could be attributed to a number of reservoir flow and fracture mechanisms. These include:

1. Condensate dropout as the producing well pressure is lowered. This dropout has the effect of lowering the effective permeability of the fracture and the reservoir near the well due to two-phase gas-condensate flow effects.
2. Changing conductivity of the acid fractures as the pressure declines and the effective stress on the fractures increases.
3. Changing permeability of the reservoir as the pressure is lowered and the effective stress increases.
4. Turbulence in either the fracture or reservoir in the near wellbore region.

The process of matching the Pressure Transient Analysis (PTA) tests and the long-term production performance allowed insight to comprehend these effects and identify which of these effects were important. Understanding the reservoir and modifying the appropriate variables also somewhat resolved the uniqueness of the problems related to history matches.

Study Procedure

The following were pursued during the study:

- Candidate well properties assessment and well selection.
- Flow and buildup test analysis (PTA).
- Long-term production analysis.
- Reservoir simulation and matching.
- Skin allocation.
- Sensitivity runs to determine controlling factors governing production.

During the course of the study, several experimental data points were included: reservoir geomechanical properties (k and ϕ as functions of stress), acid fracture conductivity with stress, acid fracture parameters, pressure-volume-temperature (PVT) characterization, and relative permeability.

Carbonate Reservoir Properties

Six wells were selected for the study. These six wells exhibited some post-frac productivity changes during the first 6 months of production. (It has to be mentioned that this initial productivity change is not a general phenomenon for all Khuff wells.) Reservoir and fracture data, post-frac early flow and buildup data, long-term production data and petrophysical analysis were available in the selected wells. Table 1 presents some of the basic reservoir properties.

Major Factors Affecting Production Behavior

As mentioned in the introduction, the three major factors that were investigated and used as input data, while quantifying production behavior from the wells and history matching the rate and pressure profiles, include: (1) non-Darcy effects on production, (2) pressure and in-situ stress effects on fracture conductivity and reservoir permeability, and (3) liquid dropout as pressure reaches dew point. The following sections present some of the conclusions derived from the study.

Turbulence (Non-Darcy) Effects

Reservoir turbulent flow (non-Darcy flow) is a short-range phenomenon that acts as an additional rate dependent positive skin. It is most pronounced in radial flow, high-rate wells. Typically, the introduction of a second mobile phase, such as a condensate, can increase the turbulence coefficient by an order of magnitude over the single phase turbulence coefficient[1].

	SA-1	SA-2	SA-3	SA-4	SA-5	SA-6
Gross Pay (ft)	120	160	150	155	88	160
Net Pay (ft)	62	85	100	65	25	80
ϕ (frac)	0.13	0.10	0.12	0.09	0.12	0.10
S_w (frac)	.021	0.2	0.21	0.24	0.29	0.32
k, md	2.7	1.5	3.6	1.7	2.9	1.2

Table 1. Selected gas well reservoir properties

Successful acid fracturing of the well significantly reduces the reservoir turbulence. This is because the fractures create an easy pathway for the gas to flow from the reservoir to the wellbore. Once the high flow rate is transferred to the fracture, linear flow occurs from the fracture to the well. As per design, acid fractures induced in the study wells are in excess of 100 ft in half-length. This length significantly negates turbulence effects.

Turbulence can also occur within the fracture where flow velocities are significantly high. Moreover, multiphase flow effects aggravate turbulence in fractures. Laboratory data developed by Stim-Lab[2, 3] for propped fractures, plus some additional correlative work by Martins[4] and others, show that conductivity drops in proppant treatments are quite significant. An order of magnitude drop in conductivity can occur for wells flowing at higher rates. These conductivity reductions should be readily apparent in PTA tests or in the long-term performance of such wells.

Four of the six wells analyzed had multirate tests performed on them, and all of the wells had buildups following the last rate. Gas flow rates during the tests were typically on the order of 30 MMscfd to 40 MMscfd. None of the wells exhibited any turbulence effects during any of the flow or buildup periods of the test. This probably shows the highly conductive nature of the fractures. Therefore, no turbulence effect was incorporated in the models.

Stress-Dependent Acid Fracture Conductivity

For wells that have been acid fractured, it is well established that the conductivity lessons with time as the well is produced. The conductivity is reduced due to damage and/or fracture closure depending upon the rock type. A conductivity stress relation provided in the following equations, was established on some carbonate cores:

log $C_{f1} = -k_1(\sigma_h - C_1)$: upper bound conductivity, and
log $C_{f2} = -k_2(\sigma_h - C_2)$: lower bound conductivity,

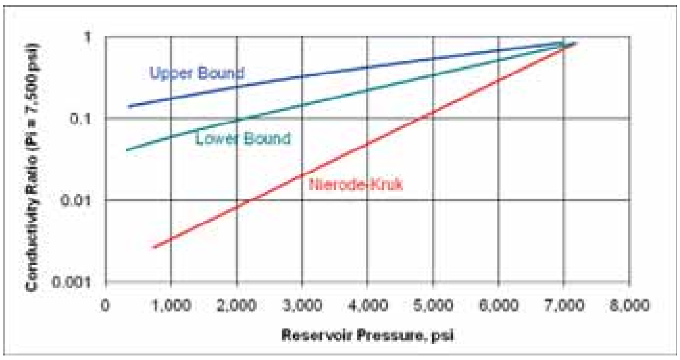

Fig. 2. Acid fracture conductivity dependence on pressure.

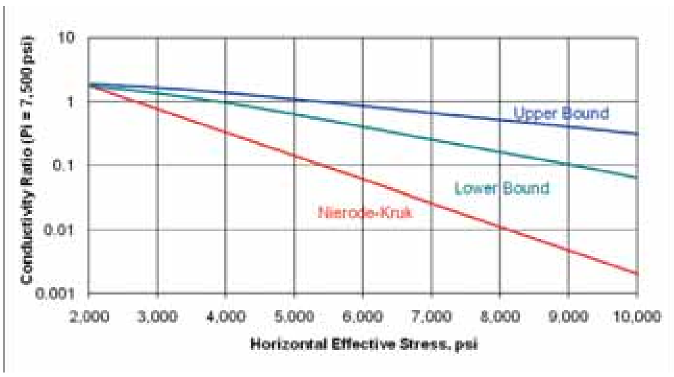

Fig. 1. Bounding normalized acid fracture conductivity.

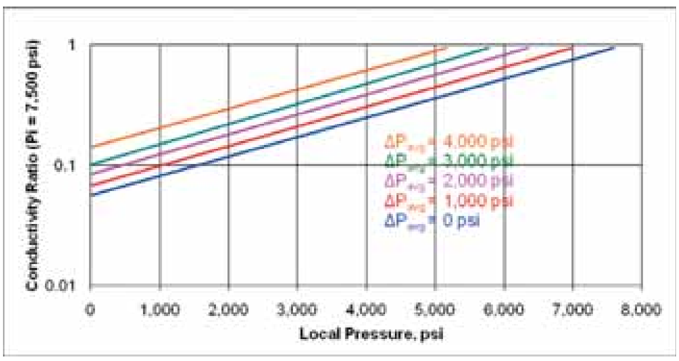

Fig. 3. Acid fracture conductivity with decreasing pressure.

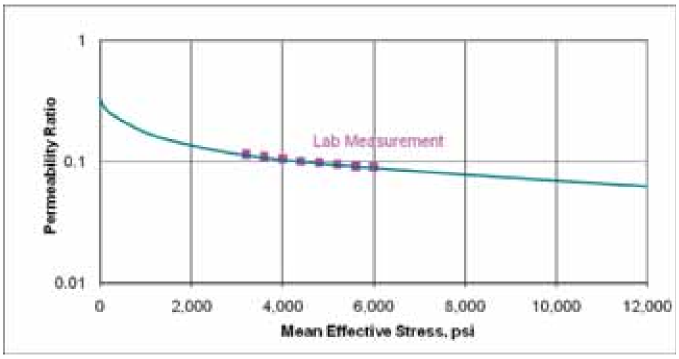

Fig. 4. Permeability dependence on mean effective stress.

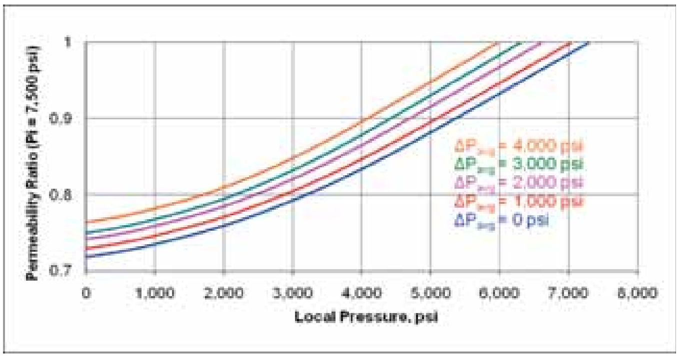

Fig. 5. Permeability dependence on pressure.

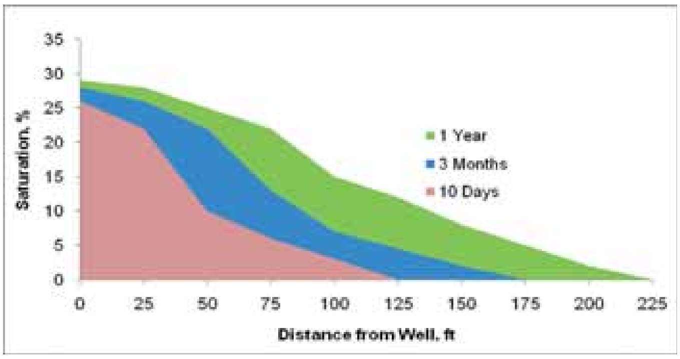

Fig. 6. Liquid dropout profile near wellbore.

where k_i and C_i are experimentally derived coefficients, and $k_2>k_1$, and σ_h represents the horizontal effective stress. These curves are normalized by dividing by a reference state. In this way, the equations can give fracture conductivity multipliers as a function of stress. Figure 1 shows the two normalized curves as a function of effective horizontal stress.

The Nierode-Kruk method[5, 6] has been used extensively in the past to estimate acid fracture conductivity. The Nierode-Kruk conductivity calculation is dependent on rock embedment strength. Figure 1 also shows the Nierode-Kruk conductivity calculated for an embedment strength of 40,000 psi as compared to experimentally derived values.

It is clear that the Nierode-Kruk values predict much greater fracture conductivity loss than either of the Saudi Aramco curves. By adjusting the value of the embedment strength used in the Nierode-Kruk method, it is possible to exactly duplicate the experimental bounding curves. The lower bound conductivity case was used as a starting point in the simulation models.

Figure 2 shows the normalized acid fracture conductivity multipliers as a function of core pressure. Increased reservoir pressure improves the state of in-situ stress on a fracture, thereby preserving higher conductivity. Once again, the Nierode-Kruk relationship is also shown in this figure.

Figure 3 shows the normalized conductivity multipliers for the low conductivity case varying with decreasing reservoir pressure. The multiplier at the initial average pressure of 7,500 psi and a bottom-hole pressure (BHP) of 2,000 psi is about 0.12. The effects of in-situ stress and reservoir pressure are incorporated in the simulation model.

Stress Dependent Reservoir Permeability

Stress dependent reservoir permeability and porosity equations derived from lab data[7] are:

$$k_{res} = c_1 x k_{ambient} x (\sigma + C_2)^{c_3}$$

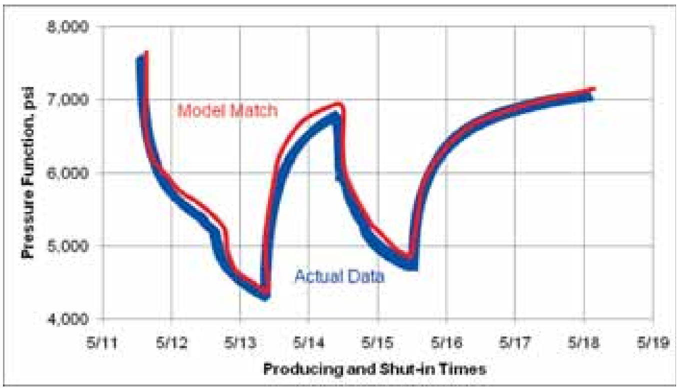

Fig. 7. Flow and buildup test history match.

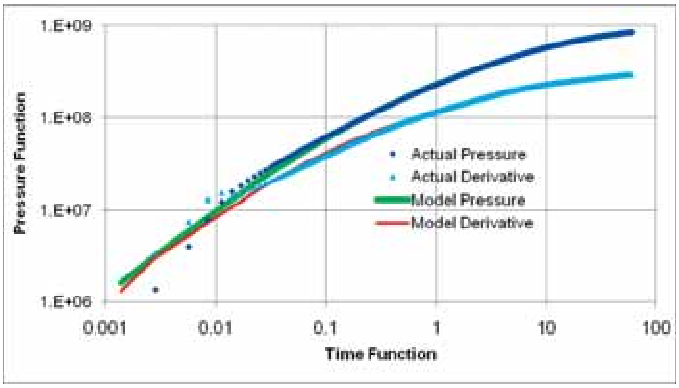

Fig. 8. Pressure and derivative history match.

Flow Period	Duration, hours	Gas Rate, MMscfd
1	25	30
2	18	40
3	25	0
4	1.7	36
5	0.3	0
6	8	30
7	17	36
8	60	0

Table 2. Flow and buildup test for Well SA-1

$$kres = c_4 x \phi_{ambient} x \, (\bar{\sigma} + C_5)^{-c_6}$$

where the subscript ambient refers to the zero stress state, $\bar{\sigma}$ for mean effective stress, and k and ϕ refer to permeability (md) and porosity (fraction), respectively. C_i represents the experimentally derived coefficients. The mean effective stress is the mean total stress minus the pressure, expressed as:

$$\bar{\sigma} = \frac{1}{3}(\sigma_{1\tau} + \sigma_{2\tau} + \sigma_{3\tau}) - \alpha P$$

where α is Biot's constant, and τ is the total stress.

This reservoir permeability data, normalized to the mean effective stress of 5,000 psia (associated with a reservoir pressure of 7,500 psi), is shown in Fig. 4.

Also shown in this figure is the experimentally derived correlation from the Core Lab study[2]. Such data were included in the simulation model while running it in full geomechanics mode. In this case, the model is calculating stresses directly, and the appropriate permeability multiplier was determined from the mean effective stress.

The core stress dependent data can be made a function of the pressure within the core, assuming a reasonable set of boundary conditions for the stress calculation. Normalized results are shown in Fig. 5 where the reference point is the initial reservoir pressure of 7,500 psi.

As the reservoir pressure declines, the mean total stress also declines. This is observed in the field, in that the fracturing pressure at the well decreases if the well is re- stimulated at a later point in time after depletion has taken place. The decrease in mean total stress is smaller than the decrease in average pressure by a certain factor, and therefore the effective stress in the far field increases and permeability decreases.

The situation is different around the wellbore. If a well flows at a constant BHP, then the maximum mean ef-

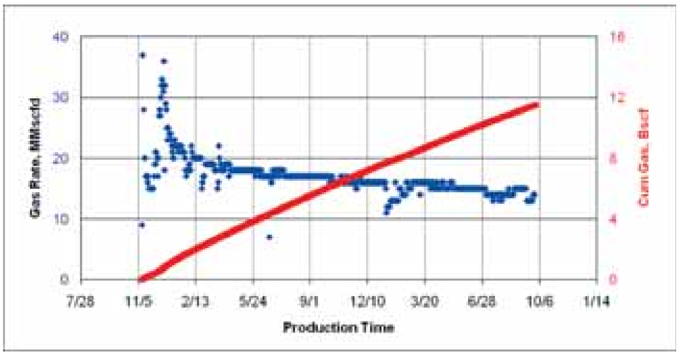

Fig. 9. Rate history, Well SA-1

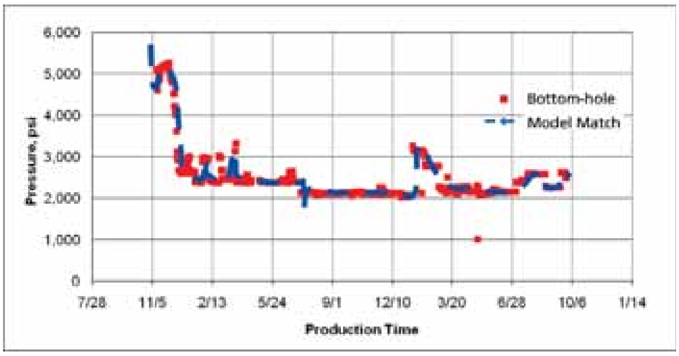

Fig. 11. History match pressure data for observed production.

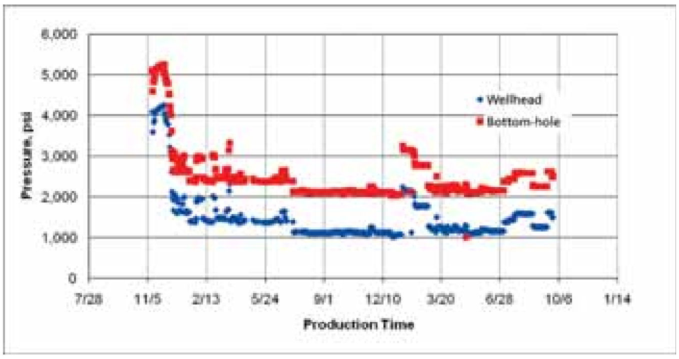

Fig. 10. Pressure history, Well SA-1

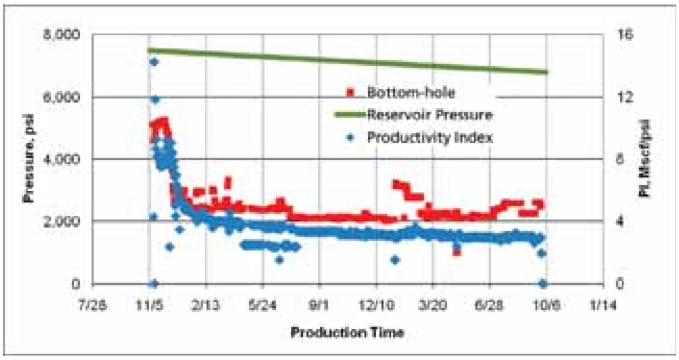

Fig. 12. PI and reservoir pressure vs. time, Well SA-1.

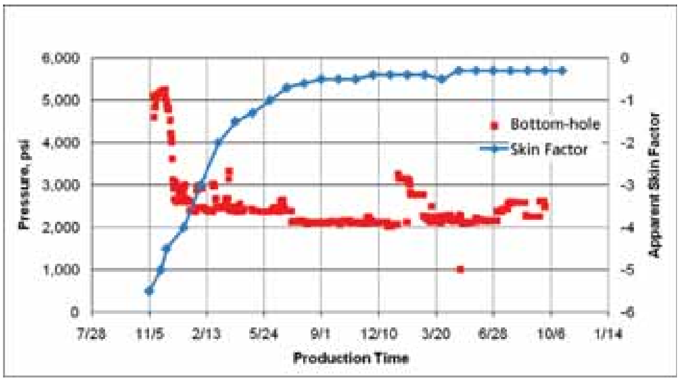

Fig. 13. Total skin factor and BHP, Well SA-1.

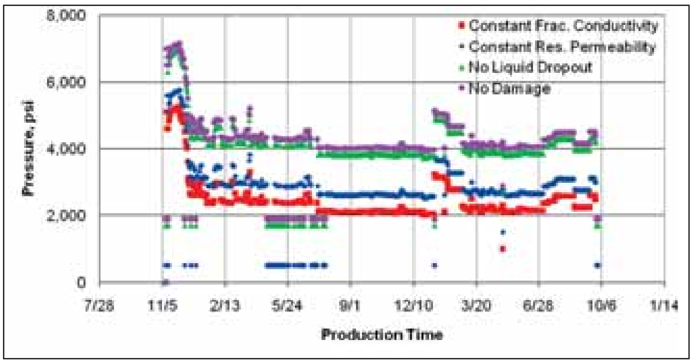

Fig. 14. Skin effects on pressure behavior.

Well	Total Skin	% Skin due to Liquid Dropout	% Skin due to *k* Decrease	% Skin due to C_f Loss
SA-1	4.1	64	35	1
SA-2	4.8	64	35	1
SA-3	1.6	51	48	1
SA-4	1.54	48	48	2
SA-5	6.2	36	28	35

Table 3. Skin allocations for gas well deliverability

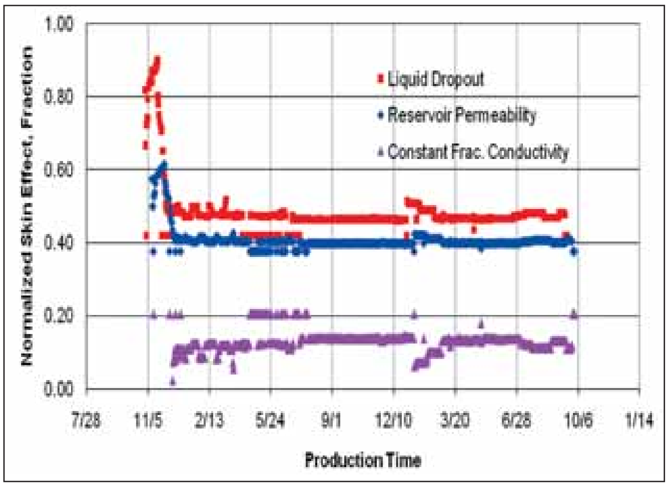

Fig. 15. Normalized skin allocation for an example well.

fective stress at the well occurs at time zero and decreases as the average pressure declines. Therefore, the permeability first drops, due to initial drawdown, and then slowly recovers during depletion. For the subject wells, the minimum flowing BHP is around 2,000 psi. The maximum reservoir permeability multiplier in this case will be around 0.77.

A laboratory derived porosity equation relating ϕ_{res} to $\phi_{ambient}$ was previously shown. A simpler approach was taken to represent porosity impact. Pore volume compressibility was calculated from the porosity equation. An average value of 3.0 x 10^{-6} 1/psi gave the best fit for porosity ratio vs. pressure. The gas compressibility from the PVT data was estimated to be 79.0 x 10^{-6} 1/psi, which is an order of magnitude larger than the pore volume compressibility. Therefore, the pore volume compressibility is small in comparison and there was no need to account for it by using a more complex stress formulation. A value of 3.0 x 10^{-6} 1/psi for pore volume compressibility was used in the study. The change in porosity within the model is then calculated in a manner analogous to a conventional black oil simulation model.

Liquid Dropout

As the pressure goes below the dew point, the liquid (condensate) drops out in the reservoir, particularly near the wellbore, thereby causing a reduction of relative permeability to gas. This causes a decrease in production. Simulation studies have shown that the near well condensate saturation can quickly reach over 30% within 200 ft to 300 ft of the radius, Fig. 6.

The effect of liquid dropout was modeled based on reservoir and fluid properties for history matching pressure and production behavior.

Analysis Procedure

The model was first built considering petrophysics and other reservoir and geological factors. Next, permeability, k, dimensionless fracture conductivity, F_{cd}, and fracture half-length, L_f, were estimated from stimulation analysis and reservoir data. The reservoir simulation model was then built with $k_{res} = f(p_{avg},p)$and $C_f = f(p_{avg},p)$, and with liquid effects on gas relative permeability, k_{rg}.

A history match PTA test was then performed with the reservoir simulation model. The well drainage area was determined from production analysis. The long-term production performance was then history matched by adjusting drainage area, k_{rg}, and dew point pressure. The total skin factor defined by the summation of skin due to liquid dropout, permeability loss, and conductivity loss was next decoupled. Sensitivity runs were made using multilayer models with full or no geomechanics (radial models were also used).

Base Pressure Transient Analysis

Measurements during several flow and shut-in periods were performed for Well SA-1, as given in Table 2. Each portion of the data was analyzed.

A history match was performed; Fig. 7 presents the flow and buildup test match and Fig. 8 presents the pressure and derivative match. This match was very reasonable using average fracture parameters of 100 ft and the F_{cd} of 100, which were close to the original design parameters. The match was obtained using zero turbulence and multipliers for both reservoir permeability and fracture conductivity. The reservoir properties, such as kh and P_{avg}, were all within an acceptable range of accuracy.

Turbulence effects were not present in the data. For stimulated wells experiencing linear flow and turbulence, there tends to be a hump in the early time derivative after coming out of wellbore storage and transitioning into linear flow. This hump is similar to the hump in a radial flow model when there is a positive skin. In practice, this hump can also be interpreted as fracture face skin or to a "choked" fracture[8]. Also, the conductivity to match both the last flow period and the buildup is very high, indicating an infinite conductivity fracture. This is inconsistent with a turbulent flow situation. Qualitatively we can state that turbulence does not appear to be present in the test.

The residual oil saturation, S_{org}, which has a very significant impact on late time performance, does not matter in the interpretation of this well test (or, for that matter, in any of the other well tests to be analyzed). The amount of production below the dew point is insignificant.

Productivity Analysis

The gas rate, cumulative production and pressure behavior history for Well SA-1 are provided in Figs. 9 and 10. The following controlling parameters were used to match the production and pressure data for this well, Fig. 11.

- Liquid drop out near the fracture.
- Reservoir permeability reduction.
- Conductivity loss in the fracture.

For the match shown in Fig. 11, Fig. 12 presents the reservoir pressure and PI vs. time for Well SA-1, assuming a drainage area of four square miles. The PI is constant at late times at a skin of -0.5. The total skin factor with time is presented in Fig. 13. The flowing material balance (FMB) plot[9] was used to determine the drainage area and all variables presented in these figures contributed to the match shown in Fig. 11.

Partitioning of Skin Effects

The skin factors are time dependent and can be combined to represent the pseudo-total skin, $\Delta S'(t)$, given by the equation: $\Delta S'(t) = \Delta S_{dropout}(t) + \Delta S_{permloss}(t) + \Delta S'(t)$. Due to the nonlinearity of the skin factors, they are not additives, and therefore the pseudo-total skin, $\Delta S'(t)$, is only an approximation of the true total skin, $\Delta S'(t)$.

It now remains to determine the relative significance of the three identified productivity loss mechanisms in the match. The goal is to quantify the skin increase of each of the constituent parts with time. The following variations of the history match were performed to ascertain the contribution from the individual variables:

1. Remove the liquid by setting the solution's oil-gas ratio to 0.0 (remove liquid damage).
2. Remove the pressure-dependent reservoir permeability only (remove reservoir permeability loss).
3. Make the fracture conductivity constant at the initial fracture conductivity (remove fracture conductivity loss with pressure).
4. Remove all of the above effects in one final run (no damage case).

For each run everything else was maintained at the history match values. A chart of the BHP vs. time for these cases is given in Fig. 14.

The calculated pressure is virtually identical for the history match and the case with constant fracture conductivity. Therefore, the fracture conductivity loss does not contribute to an increase in skin. This is because the fracture conductivity still remains high at the end of the production period.

The skin effects can be normalized to the sum of the constituent parts and are shown for an example well in Fig. 15. Liquid dropout accounts for the highest increased skin; geomechanical reservoir permeability loss accounts for a moderate contribution to increased skin; and the fracture conductivity loss accounts for the lowest incremental skin. Skin is directly proportional to the additional pressure drop associated with a particular damage mechanism.

The fracture conductivity loss during the production time for the wells we studied does not contribute to additional skin damage. This is because the remaining conductivity after the loss still provides a high value of Fcd. In one example studied, the initial F_{cd} of the fracture was 110. The fracture conductivity multiplier at this later time was 0.15 and the k_{rg} in the fracture was 0.85 for a combined multiplier of 0.13. The calculated F_{cd} was therefore 14, which is still high, and the fracture has near infinite conductivity characteristics, however, if F_{cd} drops below a certain limit, the well will start behaving like a well without any stimulation treatment, which will adversely affect productivity and gas recovery.

The skin allocations for Wells SA-1 to SA-5 are provided in Table 3. Only one well shows some damage in the induced fracture that contributes to the rate behavior of the well.

Conclusions

A few possible mechanisms impacting production behavior have been investigated in this study. Those include: (1) Turbulence or non-Darcy effects, (2) Fracture conductivity loss due to increasing effective stress at the well, (3) Reservoir permeability loss due to increasing effective stress from production at the well, and (4) Condensate dropout as pressure drops below the bubble point. The following conclusions can be drawn based on our investigation and are limited to the particular field and well configuration only.

1. Although, in proppant fractured wells, the skin, due to turbulence or non-Darcy effects is dominant, it was found to be unimportant for the acid fractured cases.
2. The overall productivity behavior was quantified as dependent on the changing skin factor and as a function of time for each well. This skin was allocated to the following three main mechanisms during history matching: fracture conductivity, reservoir permeability and liquid dropout.
3. The majority of the skin increases occur in the first few months of production, and stability is reached after that time.
4. A few wells whose early production data indicated an initial decline followed by production stabilization were mostly impacted by the liquid dropout and effects of in-situ stress and pressure on reservoir permeability. More assessment with longer term production performance is needed to confirm the initial results.
5. When fracture conductivity degradation is not an issue, and the presence of induced fracture is confirmed, refracturing cannot be recommended for productivity restoration.

Acknowledgements

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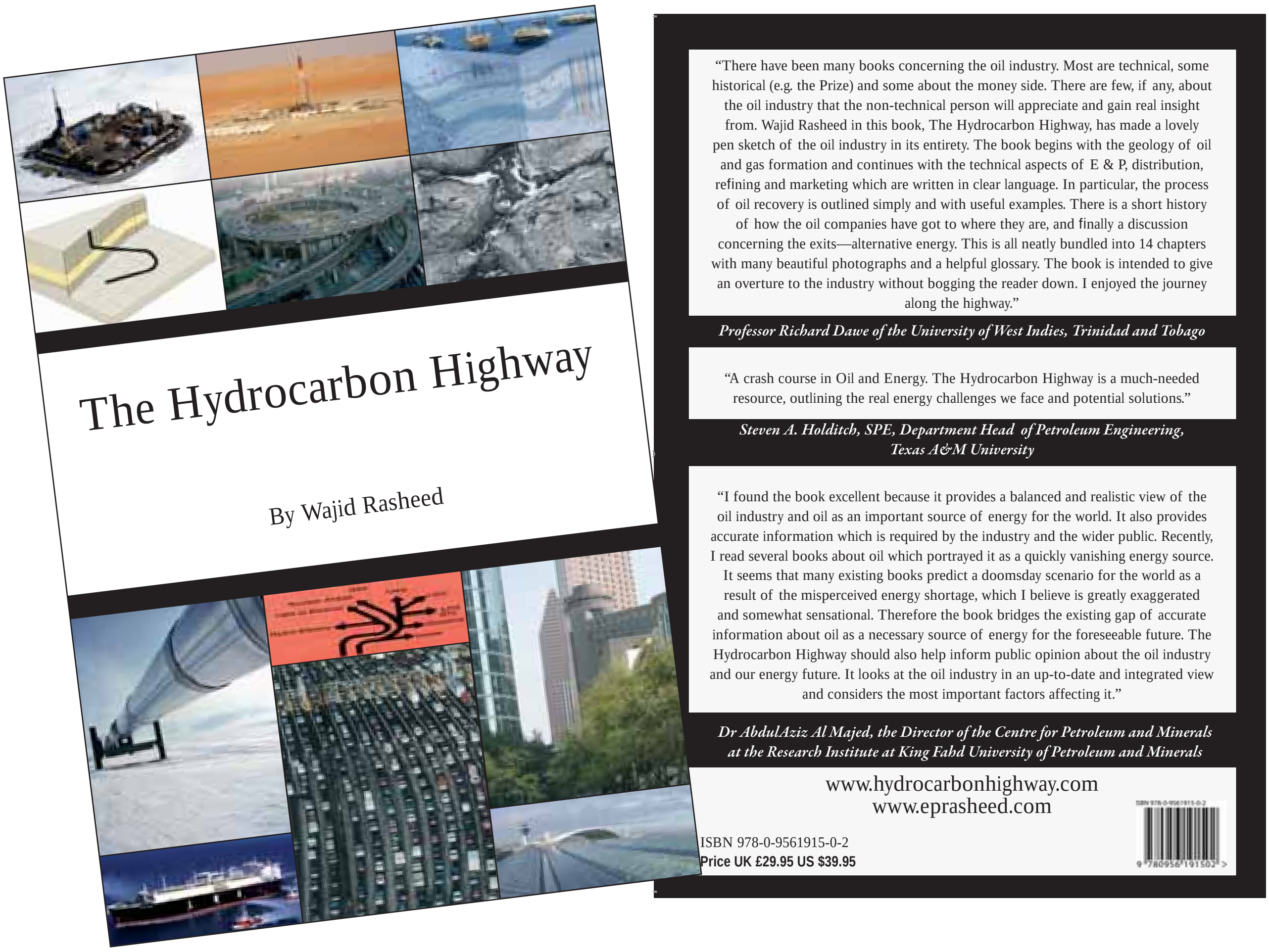
Paper Barrels – Oil and Gas Markets



'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

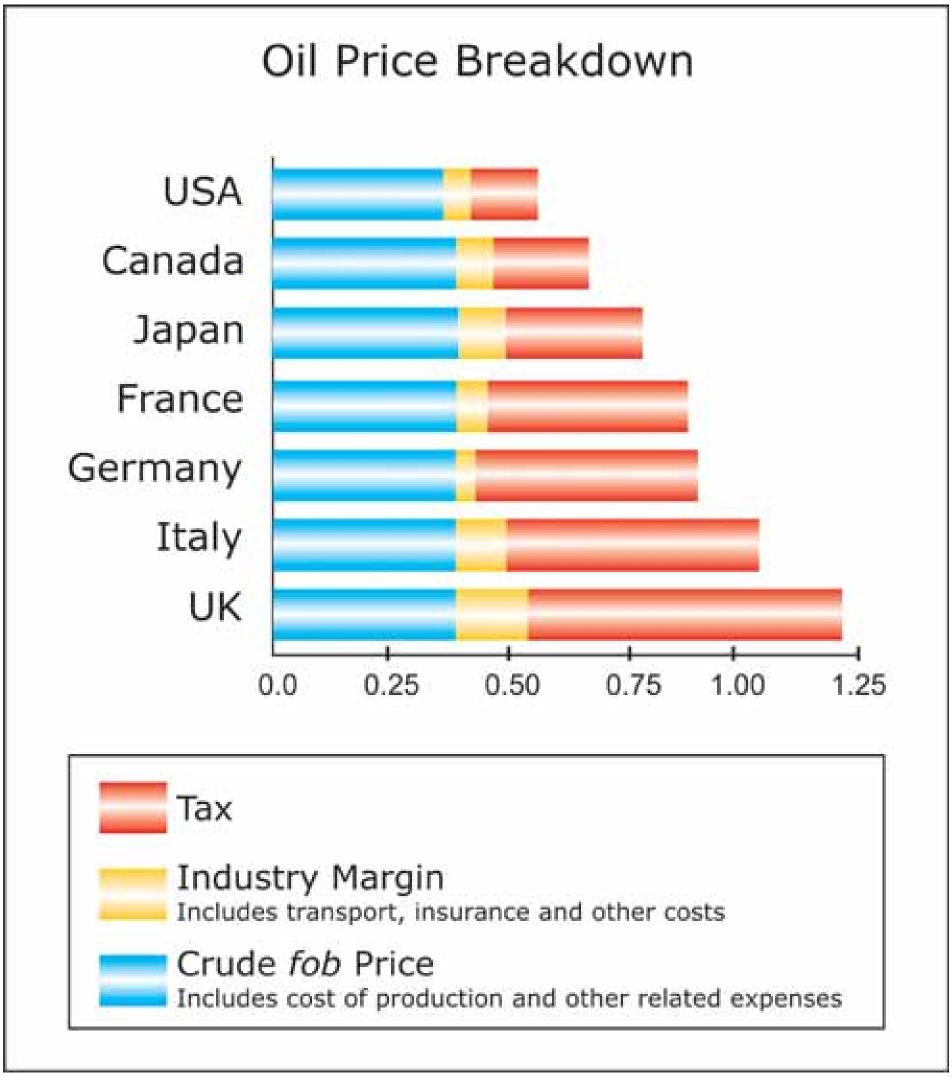


Figure 1 - Oil Price Breakdown (OPEC)

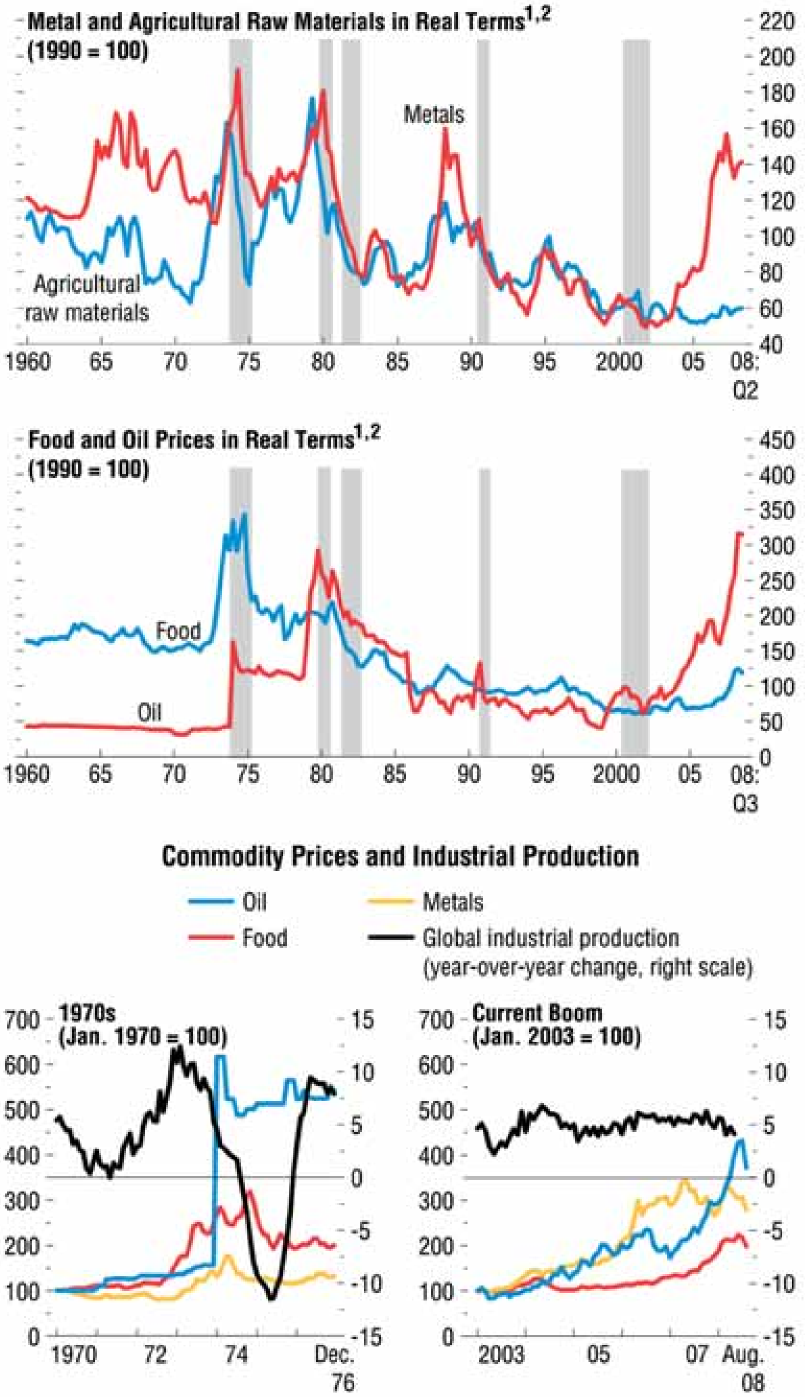
premium. Oil is no exception to the quality rule, yet the prevailing stereotype is that a group of oil barons in Dallas or oil sheiks in Dubai control prices behind closed doors. Thankfully, the reality is somewhat more transparent with petroleum prices being determined by market forces, quality and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

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

• 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. $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.

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

Every day 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 sup-

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

ply. 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 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% 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.

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 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.

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 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

> "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."

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].

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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.


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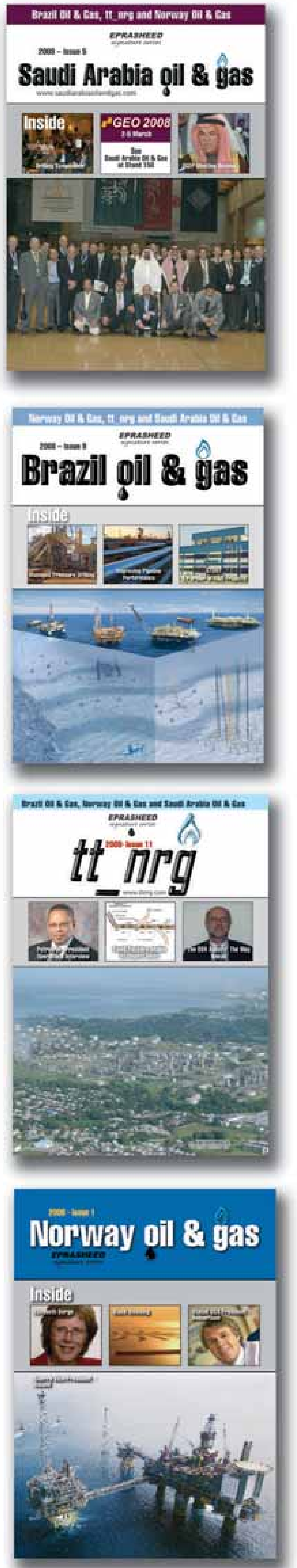
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