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Saudi Arabia oil & gas

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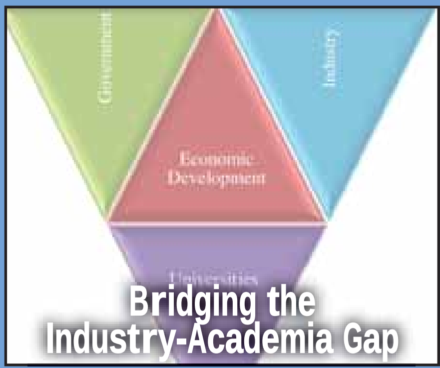

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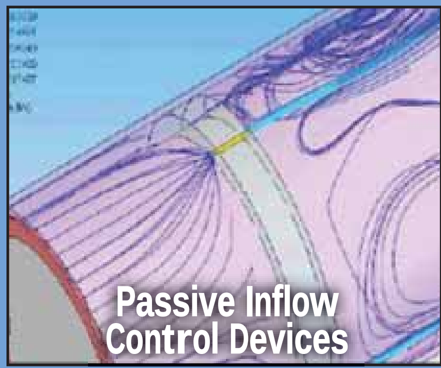
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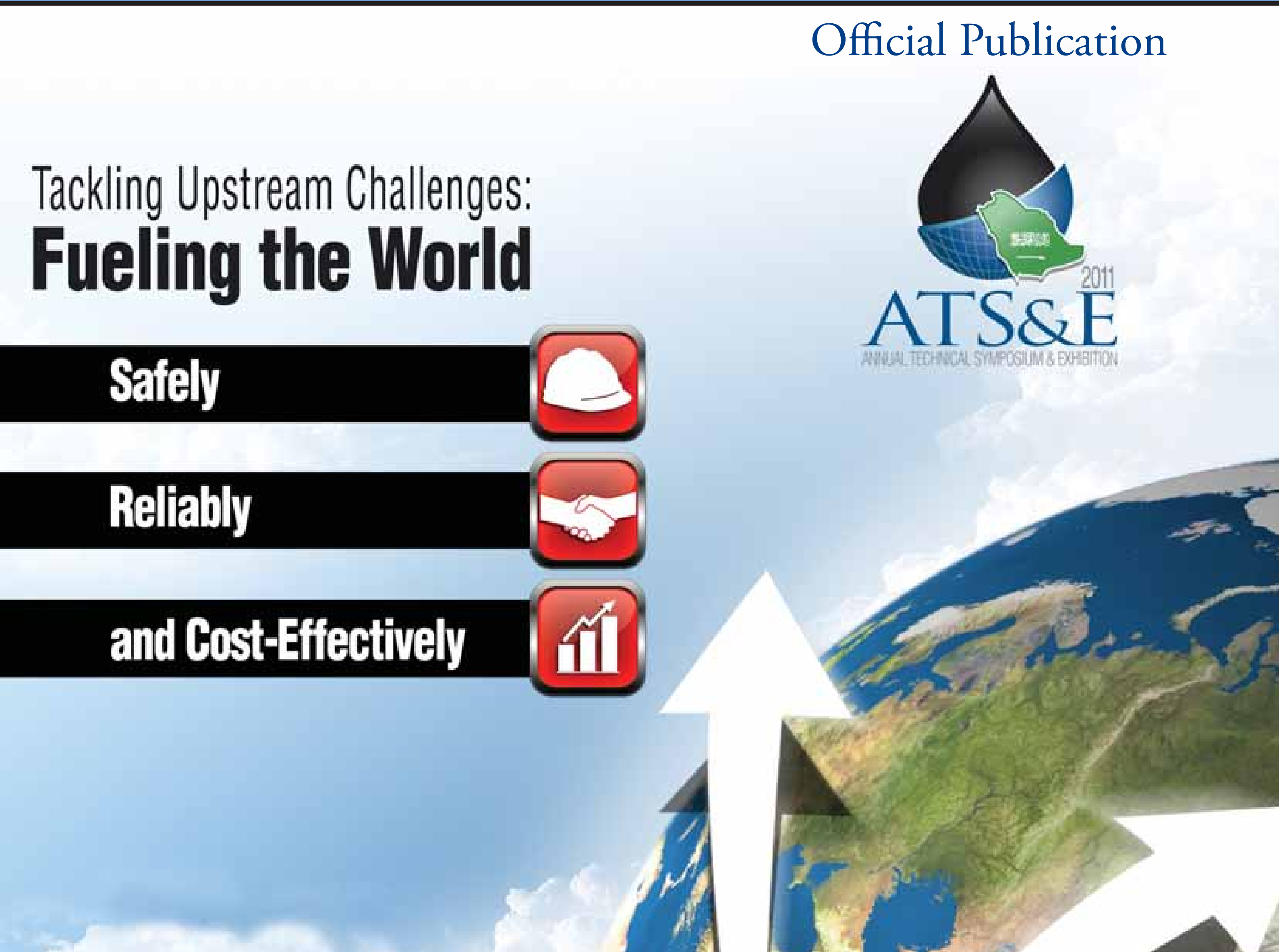

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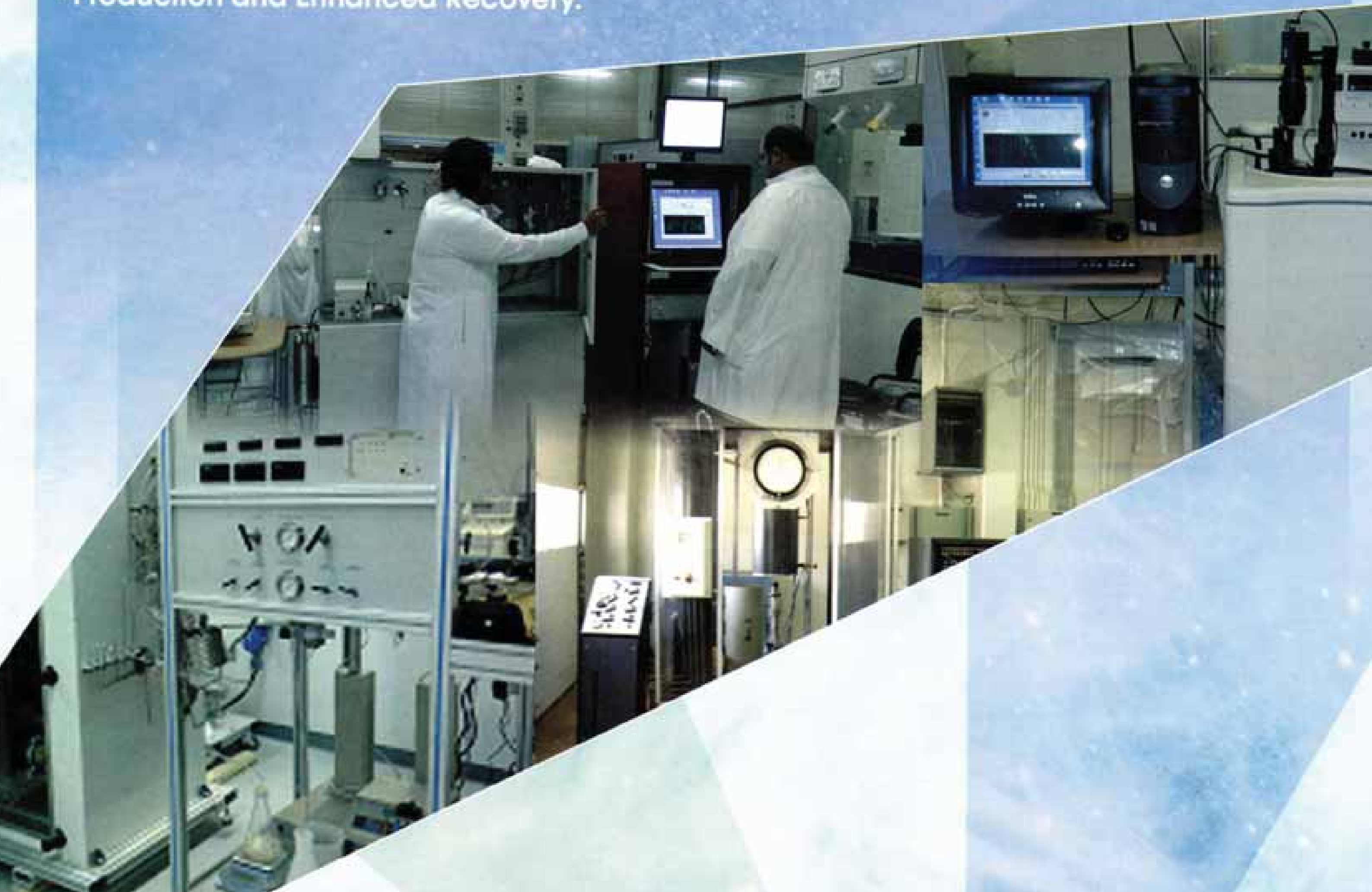
- Reservoir Characterization and Numerical Simulation,
- Drilling Engineering,
- Rock Mechanics,
- Production and Enhanced Recovery.



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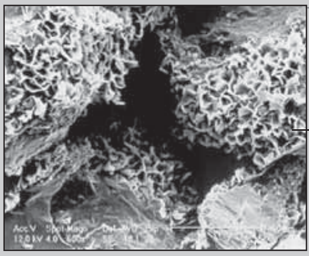

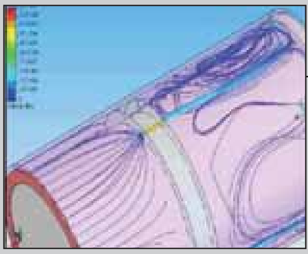

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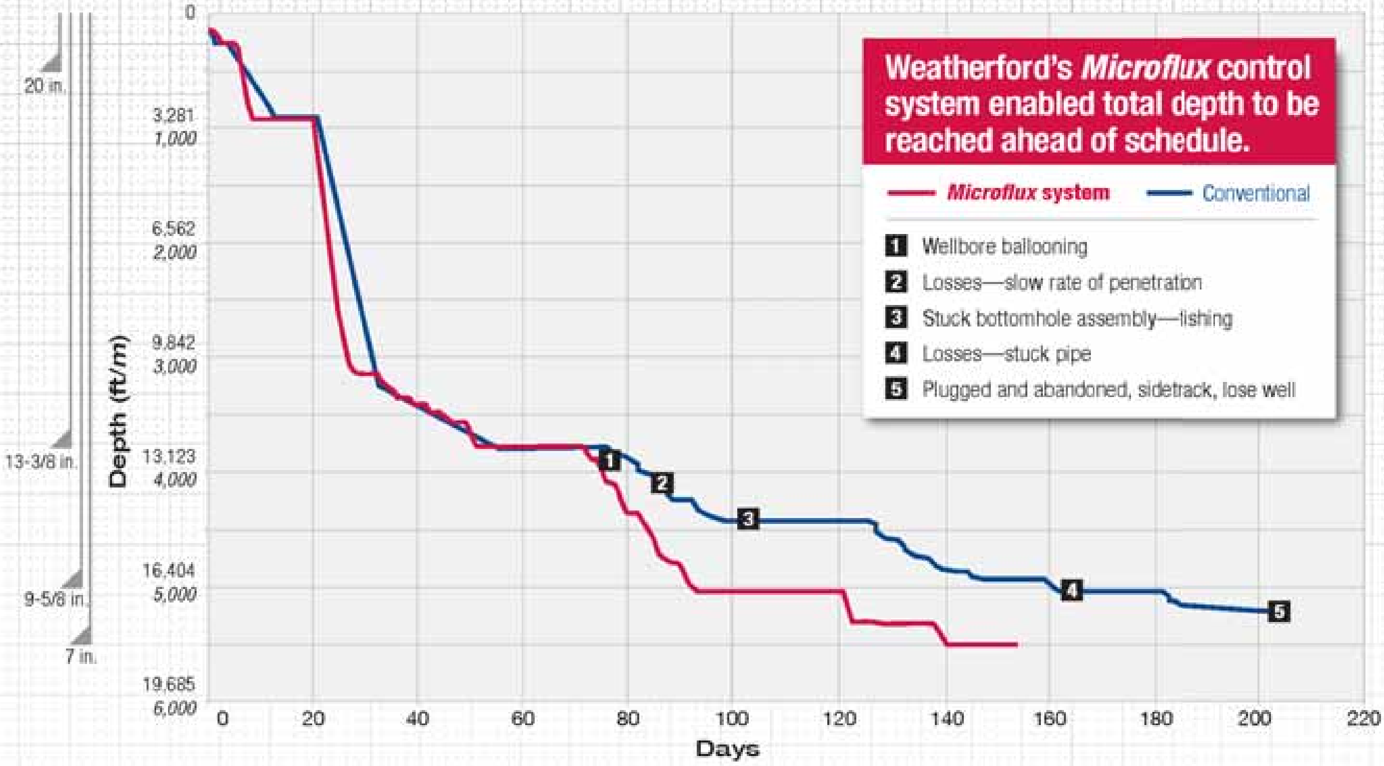

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CO_2, Unconventional Gas Eyed at Workshop

By Heather Bence.

Representatives from Stanford University, King Fahd University of Petroleum and Minerals and Saudi Aramco recently gathered for a two-day workshop focusing on collaboration in two strategic areas: unconventional gas and CO2 injection. The workshop follows in the footsteps of a recently signed memorandum of understanding signed by the three organizations.

DHAHRAN, April 27, 2011 – The EXPEC Advanced Research Center (EXPEC ARC) recently hosted a two-day trilateral workshop involving more than 50 scientists, professors and engineers from Stanford University, King Fahd University of Petroleum and Minerals (KFUPM) and Saudi Aramco.

The workshop was the first event to be held following the recently signed memorandum of understanding (MOU) among the three organizations.

“EXPEC ARC proactively seeks to partner and collaborate to find high value technology solutions,” said EXPEC ARC manager Samer AlAshgar. “Our newly established strategic partnership with KFUPM and Stanford University has achieved a strong start in addressing select, targeted challenges within our upstream operations.”

The workshop aimed to extend collaboration in two strategic areas: unconventional gas and CO_2 injection. The first day focused on challenges and opportunities related to unconventional gas, including tight gas, shale gas and technologies related to fracturing, productivity enhancements and reservoir characterization.

Topics of discussion during the second day included challenges in CO_2 injection and sequestration, enhanced oil recovery, simulation of CO_2 fluid-fluid and fluid-rock interactions, monitoring techniques and seismic applications.

> “… the partnering organizations are working to establish sustainable strategic research and development programs in specific areas of the upstream oil and gas industry”

“The workshop provided a lively forum for all members to meet and gain a full understanding of key reservoir engineering challenges at Saudi Aramco,” said Abdulaziz O. Al-Kaabi, chief technologist of the EXPEC ARC Reservoir Engineering Technology Team. “Several topics have been short-listed and are currently undergoing prioritization, following which specific projects will be outlined for collaborative research.”

The three parties entered into a trilateral collaboration agreement earlier this year to establish a strategic relationship in education and scientific research in geosciences and petroleum Engineering.

As such, the partnering organizations are working to establish sustainable strategic research and development programs in specific areas of the upstream oil and gas industry.

Oil & Gas Supplier Forum Held in Houston

By Judi Ottmann.

HOUSTON, April 27, 2011 – Aramco Services Co. (ASC) hosted an Oil and Gas Supplier Forum recently, providing an overview of Saudi Aramco and its critical material needs to an audience of suppliers and manufacturers from throughout the Western Hemisphere.

As they exit the ASC Auditorium after the forum presentations, participants provide their company information to Beatrice Garza with ASC Procurement and Logistics.

Coordinated by ASC's Procurement and Logistics (P&L) Department, the event in March exceeded planned capacity with 104 participants representing 78 companies. Eighty-three took part in the on-site session, and 21 tuned in via videoconferencing.

Representatives from ASC provided an overview of Saudi Aramco's business supply needs to support its current operations and expansion projects.

They also outlined quality requirements for manufacturing plants, new contracting procedures for 2011 and discussed the registration-and-approval process involved in becoming a qualified supplier.

ASC speakers were: P&L representatives Mohammed Al Belushi, manager; Dewayne Walker, event coordinator; Jacklyon Edwards; Rusty Wittmann and Karl Volkmann.

Tech Services representative Julio Valdespino of Quality Systems also was a presenter. The forum concluded with a networking luncheon.

Saudi Aramco and Korea: Mutual Benefits, Shared Opportunities and Enduring Relationships

By Khalid A. Al-Falih, Saudi Aramco President & Chief Executive Officer, at the Korean Chamber of Commerce.

SEOUL, April 26, 2011 -- *Anyoung hashim nika, Yoro bon bankaps hamnida.* Distinguished guests, ladies and gentlemen, good morning. I would like to thank Chairman Sohn for his gracious invitation and warm hospitality, and to express my appreciation to each of you for your attendance this morning.

Ladies and gentlemen, today I will be discussing Korea's current and future energy mix, the significant role Saudi Aramco plays in meeting this nation's demand for energy, and the ways in which the drivers of Korea's Green Growth strategy for economic development are aligned with my company's view of sustainability.

I will also explore the degree to which Saudi Aramco relies on Korean firms for outstanding services and high-quality goods, and outline the many opportunities that Korean companies will find in Saudi Arabia in coming years.

I will close by sharing my thoughts on the future trajectory of those relationships, and the prospects of further enhancing the already strong ties which draw us together—for the benefit of both our societies.

Allow me to begin, however, by sounding a note of admiration for the accomplishments of this great nation and its people over the last half century. What the world has come to know as "The Miracle on the Han River" is truly nothing short of incredible and awe-inspiring.

I believe every nation can learn from the Korean experience when it comes to how you achieved industrial development and infrastructure building; technology, innovation and high quality education; value addition through knowledge; and managing both economic and social change while maintaining pride in your rich heritage and traditions.

As both Korea and Saudi Arabia have witnessed rapid economic and social development over the last fifty years, and are now both members of the G20 group of leading economies, "The Land of the Morning Calm" has a particular relevance for us in the Kingdom.

The ways in which this country has demonstrated its resilience during times of economic distress are also admirable, as Korea always seems to emerge from periods of difficulty stronger than before, and with even greater competitiveness in the global marketplace. The manner in which Korea weathered the recent global economic crisis adds to the admiration Saudis hold for this nation.

But our respect is not limited to the amazing GDP growth numbers and the technological breakthroughs coming from Korean companies and research institutes. There is also an incredible degree of respect for Koreans among Saudis at a human level, because for more than a generation we have seen first-hand your work ethic, your fortitude, your ingenuity, and the way

> "Energy is the lifeblood of developed nations and the foundation of our modern way of life, and advanced economies like Korea depend on a plentiful and reliable supply of energy to remain vibrant and vigorous."

in which Koreans meet their responsibilities and honor their commitments.

Saudis have also come to appreciate the quality and ingenuity of Korean products, and it is rare to find a Saudi home without a Korean television set or air conditioner, Korean-made mobile phones or laptops, and often a Hyundai, KIA, Daewoo or SsangYong car or SUV in the driveway. In fact, this country is now among Saudi Arabia's four largest trading partners.

In addition, many Saudis follow Korean athletes and entertainers on the world stage, and are rooting for PyeongChang's bid to host the 2018 Winter Olympics. However, the one place where Koreans have been anything but friendly to us is on the football pitch, as the Red Devils knocked Saudi Arabia out in the qualifying stages for last year's World Cup!

I believe there is a similar affinity for Saudi Arabia and Saudis here—and in fact I have met Korean gentlemen of a certain age who, once they know where I am from, delight in telling me about their experiences in the Kingdom as young men, helping to construct vital infrastructure.

Many of those Korean-built installations—from petroleum plants and industrial complexes to transportation networks and power grids—are still there, standing strong: a testament to both the quality of workmanship and the commitment of the Korean workers.

By the same token, at Saudi Aramco we are proud to have contributed to Korea's phenomenal growth and development through our reliable supply of petroleum, and through our equity stake in the S-Oil Corporation, one of this country's leading energy enterprises. This year marks the twentieth anniversary of that milestone investment—Saudi Aramco's first in Asia.

In the subsequent two decades, we and our partners have experienced both exhilarating heights and sometimes discouraging lows, but we have always remained faithful to the company, its employees, and the consumers and communities which it serves.

In fact, S-Oil is now expanding the capacity of its world-class refinery in Ulsan to more than 650,000 barrels per day, making it one of the world's biggest and most sophisticated refineries.

In addition to fuels meeting the most stringent international specifications, the facility also produces a range of highly valuable petrochemicals which help to feed many of Korea's most important industrial enterprises, and its massive new Number Two Aromatics Complex—which began trial runs this month—will make S-Oil one the largest producer of paraxylene in the entire Asian region.

I would also like to note that this week, Saudi Aramco's Board of Directors is meeting for the first time in Korea—though our Executive Committee has met here before. That's not just because S-Oil and Korea are an important part of our proud past, but rather because this market is very much a cornerstone of our company's future.

Today, the Far East is the destination for two out of every three barrels of crude oil that Saudi Aramco exports; companies from Korea and other Asian nations are important suppliers of top quality goods, materials and services to our operations; and we are seeing increasing volumes of foreign direct investment from Asia into the Kingdom.

In fact, our strategic analysis of our future business growth takes special note of the continually growing industrial might of northern Asia, encompassing such economic powerhouses as Korea, China and Japan.

Therefore, it is clear to us at Saudi Aramco that we will continue to play a fundamental role in satisfying Korea's future energy needs. Energy is the lifeblood of developed nations and the foundation of our modern way of life, and advanced economies like Korea depend on a plentiful and reliable supply of energy to remain vibrant and vigorous. Today, this country draws on fossil fuels to meet about 82 percent of its energy needs, and roughly half of the fossil fuel total comes in the form of petroleum: some 2.2 million barrels per day.

As Korea's largest supplier of oil, Saudi Aramco provides nearly a third of that total, and thus accounts for a sizable proportion of the country's overall supply of energy—helping to fuel continued economic growth and enabling the high living standards which Koreans enjoy.

Consider for a moment that Saudi Arabia meets some ten percent of the world's crude oil needs—but more than three times that percentage when it comes to this nation's oil demand. By the same token, Korea accounts for roughly one-and-a-half percent of global GDP, yet it receives something like 10 percent of our total petroleum exports. To me, those numbers indicate a high degree of affinity and a rock-solid energy relationship between Korea and the Kingdom.

That will continue to be the case for many years to come, as renewables are projected to grow from less than two percent of Korea's primary energy consumption today to around 11 percent by 2030 under the most aggressive assumptions.

It is, of course, a similar story elsewhere around the world, where the role of renewables will certainly grow but will do so gradually, given the small base from which these supplies are starting and the various economic, environmental, infrastructure and consumer acceptance hurdles which they face.

At the same time, most of the growth in renewables will come in power generation, meaning Korea's transportation and industrial sectors will rely primarily on petroleum for decades to come—and Saudi Aramco will continue to be here to meet those future needs, just as it has for decades past.

Furthermore, the Kingdom's commitment to maintaining a sizable cushion of spare crude oil production capacity— at least one-and-a-half million barrels per day, and which has reached up to four million bpd over the last couple of years —is an important stabilizing factor for the oil markets, and by extension for the global economy as a whole.

Given recent events in some oil producing countries, this additional capacity has been critical in reassuring consumers of available supplies of oil—and as Saudi Arabia's Minister of Petroleum & Mineral Resources, His Excellency Ali Al-Naimi, has made clear, the Kingdom will continue to act in support of oil market stability and as a force for moderation.

Of course, issues of supply are only part of the energy equation. Recently, I have spoken at length about the need for balancing the energy triangle of adequacy, affordability and acceptability of energy, and the need for petroleum companies to simultaneously meet all three of these imperatives in order to be truly successful. I believe these same drivers underpin much of Korea's Green Growth strategy, championed by President Lee, and I look forward during my time in Seoul to learning more about the degree to which these visions are aligned and complement one another.

> "Korean companies are among the most significant suppliers of material and equipment to our oil, gas, refining and petrochemical projects in the Kingdom, as well as providers of engineering, procurement and construction services and solutions."

However, like President Lee, we believe that there are unbreakable connections and close interrelationships between energy, economic growth, environmental stewardship and social prosperity. Likewise, we too argue that enhancing energy efficiency and promoting the rational use of renewable forms of energy have an important role to play in making wiser and better use of the various energy resources which mankind has at its disposal.

In fact, the Kingdom itself is also developing renewables—in particular solar, which given Saudi Arabia's plentiful sunshine, wide open spaces, and abundance of white sand which can be used to produce the silica utilized in solar panels, is an extremely promising area of development.

Ladies and gentlemen, although I have thus far focused primarily on the ways in which Saudi Aramco supports Korea's growth through its supply of energy, our relationship with this country is very much a two-way street.

I say that because Korean companies are among the most significant suppliers of material and equipment to our oil, gas, refining and petrochemical projects in the Kingdom, as well as providers of engineering, procurement and construction services and solutions. So just as Korea depends to a large extent on Saudi oil, Saudi Aramco relies upon Korean companies for mission-critical goods, services and technologies.

At present, there are 89 Korean companies registered with Saudi Aramco, and over the last five years, 39 contracts valued at 11.5 billion dollars have been awarded to Korean firms. During the same period, we have purchased nearly 500 million dollars of goods and materials form Korean suppliers.

In addition, over the past decade or so Korean shipyards have built 14 Very Large Crude Carriers and five product tankers for Saudi Aramco's wholly-owned shipping subsidiary, Vela International Marine, Limited, valued at roughly two billion dollars.

Saudi Aramco is also working with KAIST, the Seoul National University, and the King Fahd University of Petroleum & Minerals to develop joint research initiatives, and for many years we have sent some of our brightest young people to Korean universities to study. Here, they not only master a technical or engineering discipline, but also learn first-hand about Korea, its language and distinctive culture, its dynamic economy and society—and above all, they come to know the Korean people.

If anything, though, the future prospects for Korean companies and institutions engaged with Saudi Arabia and Saudi Aramco look even brighter. Over the next five years, the Kingdom will spend in excess of 450 billion dollars on capital projects, while Saudi Aramco will be spending a total capital budget of roughly 125 billion dollars on our domestic and international projects over the same period.

That of course covers upstream activities including new crude oil production facilities, but Saudi Aramco isn't just about petroleum production. We are also one of the world's largest producers of natural gas, a major player in refining, and we are quickly ramping up our petrochemical activities. Allow me to elaborate.

To give you some indication of the scale of our refining portfolio, Saudi Aramco currently owns or participates in joint ventures which together account for an impressive four million barrels-per-day of refining capacity, in the Kingdom and abroad. But this will soon grow even further, and will surpass six million barrels per day, representing a 50 percent increase in our global refining capacity.

That growth will be accomplished through two new refineries already in progress in the Kingdom, and four more grassroots refineries currently being considered, including one at Jaizan in Saudi Arabia and joint-venture refinery projects being looked at in China, Vietnam and Indonesia. Furthermore, we will also grow, expand and upgrade our existing refining centers.

Similarly, some thirty years ago Aramco built the world's largest natural gas network of its kind—the Master Gas System—and since then the company has roughly doubled its throughput capacity. The system will continue to expand, exceeding 15 billion standard-cubic-feet-per-day of capacity in the next five years, when the network will encompass seven world-scale gas plants.

In support of that expansion, we continue to make new natural gas discoveries in places like the Arabian Gulf, while beginning exploration in frontier areas such as the Red Sea and the northwest region of the Kingdom. These activities are adding to our reserves of 275 trillion standard cubic feet—the world's fifth largest proven reserves of gas, in addition to the world's largest reserves of conventional crude oil.

We are also strengthening and expanding our petrochemical capabilities in the Kingdom, through a world-class petrochemical project in Jubail with Dow Chemical and a planned expansion of our PetroRabigh joint venture with Sumitomo Chemical. Together, these projects are set to almost double our chemicals manufacturing capacity.

In addition, these integrated refining and petrochemical facilities will form the hubs of new industrial clusters housing other companies engaged in conversion, manufacturing and service activities.

Beyond these megaprojects, a large number of support and infrastructure initiatives—including pipelines, bulk plants, system upgrades, environmental projects and large buildings—are planned for the coming years as we continue to expand and enhance our business and facilities portfolio.

In all these cases, we require sophisticated technology, well-honed engineering and project management expertise, and proven procurement and construction capabilities. We will also need high-tech solutions and high-quality goods and materials to complete these endeavors.

In recent years, Saudi firms have increased both their capabilities and capacities, and are able to take on a greater proportion of work on our projects. But there is still ample room for leading international companies with unique abilities and expertise—especially those which seek to collaborate and partner with local Saudi enterprises.

Therefore, Saudi Aramco's capital program holds tremendous potential for Korean companies which can meet our standards and deliver on our expectations, and I personally believe that means Korean firms of various sizes and specialties have a growing opportunity to do business with us.

The ties between Saudi Aramco and Korea's business sector—as well as with its academic and research institutions—are already solid, but with the wide range of commercial and collaborative opportunities on offer, they can grow even stronger and more varied.

However, I also believe that these cooperative bonds need to evolve with changing times and conditions in order to thrive and deepen.

> "Maximizing the amount of local content utilized in our projects and ongoing operations is an important strategy for Saudi Aramco, and is part of our mission as the Kingdom's national petroleum enterprise."

Therefore, I would like to see Korean companies adopt a forward-looking strategy in which they invest in the ability to service and maintain materials and equipment in Saudi Arabia, rather than simply supporting us and the Middle East region from over the horizon here in Korea.

Maximizing the amount of local content utilized in our projects and ongoing operations is an important strategy for Saudi Aramco, and is part of our mission as the Kingdom's national petroleum enterprise.

Thus we believe that strategic and focused foreign direct investment in the Kingdom's industrial capabilities offers win-win opportunities for both Saudi Arabia and the international companies that share our long-term view of business success and sustainability.

In fact, Korea's continuing transition from heavy industry to cutting-edge technology and knowledge-based exports, centered on intellectual property and leveraging the growing strength of Korean brands, means there is an opportunity to move some traditional manufacturing activities offshore.

This mirrors the earlier experience of the United States and Japan, and as Korea continues to climb that same path toward even greater sophistication in its product offerings, the economic benefits of offshoring grow more apparent.

At the same time, the Kingdom is working hard to develop many of the same kinds of industries and manufacturing capabilities that Korea may be exiting as it continues its economic transformation.

For aspiring investors, the list of attractive inputs available is broad: from plentiful energy supplies, access to electricity and water utilities, and abundant supplies of chemicals and minerals, to ample land, an attractive tax and business environment, and the Kingdom's central geographic location between the large markets of Asia and Europe, offering savings on transportation and other logistical costs. Then there is the growing, well-educated youth population, with more and more new entrants into the labor market each year.

This extensive list of favorable factors can make Saudi Arabia a superb location for many Korean companies looking to expand their overseas profiles.

I liken this in many ways to Saudi Aramco's own experience with Korea. Just as this nation provided us with an ideal launching pad from which to grow our presence in north Asia, I believe the Kingdom can also be an excellent springboard for Korean firms wanting to grow their presence in the fast-growing Middle East region, and beyond.

In fact, we are already seeing such far-sighted initiatives in the energy services sector with the completion this year of Samsung Saudi Arabia's Naffora Techno Valley in Jubail, which is a major center for the Kingdom's industrial and petrochemical sectors. The project includes research and engineering facilities, as well as education and training components designed to transfer high technology and project management skills.

Similarly, LG Electronics has partnered with a leading private sector Saudi firm to build an air conditioner manufacturing plant south of Riyadh which produces more than 500,000 units per year—with plans to nearly double that capacity by year-end.

I hope that other leading Korean companies will follow this new paradigm in making strategic investments in Saudi Arabia—and in the Kingdom's continued economic and industrial development—both for their benefit and for ours.

My friends, three decades ago Korean institutions and individuals alike played a major role in constructing the Kingdom of Saudi Arabia's basic infrastructure, including many of its major hydrocarbon facilities. Twenty years ago, Saudi Aramco became involved in helping to build what is perhaps Asia's greatest petroleum industry success story during the last half of the 20th century: the emergence of S-Oil as one of the sector's most profitable companies.

Then, over the last ten years, Saudi Aramco opened new doors for Korea's world-leading engineering, procurement and construction companies to work with us on an extensive slate of megaprojects and massive shipbuilding orders—and Korean companies responded by winning an incredible proportion of the contracts on offer.

This state of affairs continues to the present with ongoing oil and gas megaprojects in Jubail, Yanbu', Karan and Wasit, and we are pleased and proud to be working with many of this country's leading industrial enterprises. We also continue to purchase a sizable volume of goods and materials from Korea's manufacturing sector, and are exploring additional opportunities for research and development collaboration with this country's universities and technology sector.

Now, though, we can take these relationships to an even higher level with strategic Korean investments in various areas of the Saudi Arabian economy, including energy-related fields.

To me, such a development is simply the natural and necessary extension of a bilateral relationship which has already brought tremendous rewards to our companies, and greater prosperity to both our peoples.

Ladies and gentlemen, I understand there is a well-known Korean saying: "*Shijaki banida*", or "starting is half of the task." Previous generations of Koreans and Saudis have indeed given us a strong foundation upon which to build, and to continue our mission of seizing shared opportunities, realizing greater mutual benefits, and further strengthening the relationships which bind our companies and our two countries so closely together.

As the Korean proverb goes "*Gong zon Gong young*," we look forward to working with many of you and your companies to realize that potential and promise, just as our joint efforts to date have helped to shape our nations and indeed the global economic landscape as a whole.

Thank you for your attention this morning, and *kamsa hamnida*.

Inventors Honored at Swiss Event

Dr. Ezzat M. Hegazi receives an award for the best invention at the Geneva International Inventions Exhibition.

From left, Awad M. Al-Mofleh, technical program director; inventors Abdullah H. Al-Grainees and Dr. Ezzat M Hegazi; Dr. Omar S. Al-AbdulHamid; Yazeed A Al-Dukhayyil, coordinator of Analytical Support Division; and Abdullah M. Al-Ghamdi, supervisor of the Advanced Analytical group, celebrate the awards from the Geneva International Inventions Exhibition.

GENEVA, Switzerland, April 20, 2011 -- Saudi Aramco and Saudi Arabia inventors won 17 awards at the 39th Geneva International Inventions Exhibition.

Dr. Ezzat M. Hegazi, Abdullah H. Al-Grainees and Maha A. Sayegh from the Research and Development Center received a gold medal with distinction for their invention, "Laser Oil Fingerprinting – Desert Ray Instrument," and received a second award from the Swiss Tourism Board as the best invention at the Geneva Inventions exhibition.

The April 6-10 event was sponsored by the Swiss government, the World Intellectual Property Organization and the state and city of Geneva. There were more than 750 exhibitors from 45 countries showcasing 1,000 new inventions from companies, individuals, universities and others around the world.

More than 100,000 people visited the exhibition. Seventeen medals – four gold, seven silver, five bronze and a Geneva award – were won by King Saud University, King Abdulaziz University, King Fahd University of Petroleum and Minerals, Princess Nora University and individual Saudi inventors from around the Kingdom.

Dr. Mohammed A. Al-Ansari, director of Saudi Aramco's Technology Program, said Saudi achievement at the exhibition was due to investment by the Kingdom and the company, which provide the kind of environment that motivates innovation, patenting and talent development.

Saudi innovation, Al-Ansari said, has been converted into applicable and marketable solutions and services that are adding value, bringing high returns on investment and boosting the nation's economy and its competitive position in the world of invention and excellence.

He said Saudi Aramco had entered with just one invention to give other entities in the Kingdom a chance to show their inventions. As a result, 18 inventions sponsored by Mawhiba competed in the Geneva exhibition.

Dr. Omar S. Al-AbdulHamid, manager of Research and Development, said the Laser Oil Fingerprinting invention was a recognition on a global stage of the company's capabilities. He added that events such as this were a great way to interact, learn and expand inventors' abilities.

Hegazi said the event was a great experience to learn from and has allowed Saudi inventors to connect with others and showcase their inventions.

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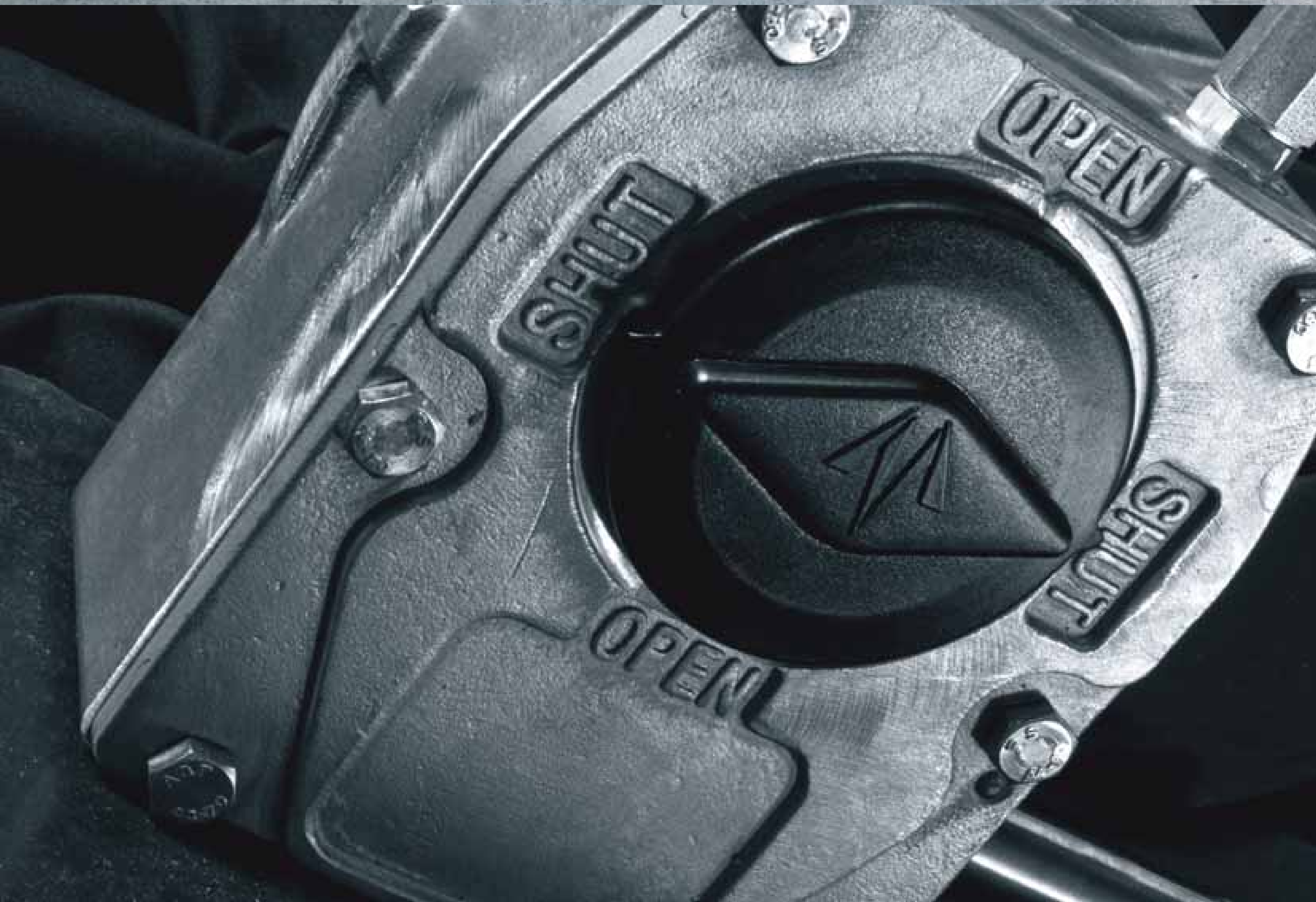

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Bridging the Oil and Gas Industry-Academia Gap

By Abdelaziz Khlaifat[1],†, Hani Qutob[1], Hamed Soroush[1], David Lysne[2] and Ola Fjeld,[3] Weatherford

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Abstract

Having different mindsets, academics and industrialists are living in different worlds and pursuing different goals. The Academic is striving for creating new solutions with a high innovation rate, scientific achievements and recognition from peers with a long range perception. The Industrialist thinks in terms of short range goals, prefers proven solutions with a low risk and is mainly concerned with costs, profits and economic survival. In view of that, the deficiency of properly skilled labor across the oil and gas industry is emerging as a significant and complex challenge to Middle Eastern countries' future development. Regardless of the large number of universities, technical graduates and post-graduates added to the workforce, only a small percentage of them are considered employable by the rapidly growing industry. Hence, the growing gap between academia and industry is reflected in the slight availability of high-quality college/university graduates demanded by the industry. This problem can be overcome by having proper and sustainable industry-academia interactions that help to pass on relevant knowledge.

Academic institutions place a great importance on closer interaction with industry and research and development organizations. Some interaction has been witnessed, in the developed countries, between large public and private sector enterprises and academic institutes at a level of industry involvement in technology development. Still, industry support for basic research is almost non-existent in developing countries. Academic institution laboratory utilization by industry for developmental purposes and for product testing has seen some success. With the establishment of in-house research centers by different industries the utilization of suh labs is on a gradual decrease. Effective collaboration between the oil and gas industry and universities will be critical to the industry economic recovery and sustainable international competitiveness. Industry must also make a sustained effort in supporting higher education by providing the support needed to help students build the employability and technical skills that are so important. The joint research venture can be successful only through proper project preparation and implementation.

In this paper, some cases of cooperation between academia and Weatherford are discussed. A number of issues key to achieving successful cooperation between industry and academia are suggested. The areas in which interaction is possible include industry support in basic research for knowledge creation, industry participation in technology development involving some exploratory work, academic intervention in solving industry problems, laboratory utilization by industry, faculty members' sabbatical leave and industry involvement in curriculum development. Also, the paper pro-

> Research alliances with industry are particularly productive because they enable involved parties to combine disparate skills and share the ultimate rewards.

poses that the oil and gas industry should work with universities to:

• Sponsor students studying subjects relevant to industrial needs.
• Offer more opportunities for internships, placements, work experience or projects.
• View working with universities as part of core innovation activity.
• Integrate an academic research group and an industrial development team to generate useful research results and solutions.

Introduction

The reduction of universities' revenues and rising costs for campuses are driven by different factors: the soaring expense of need-based scholarships; declining financial support from governments preoccupied with other budget problems; the massive spending needed to bring/keep libraries, classrooms, and laboratories up to date in our information technology age; the pressures of maintenance and repair costs; and the price of star faculty members (in addition to the regular salaries of tenured professors, regardless of their performance). Then there is competition for students from for-profit universities, providers of on-line education, and corporations' own training programs. To overcome financial problems universities have no other choice but to commit themselves much more seriously than they have done so far to begin a process of redesigning/reinventing themselves.

The universities can reinvent themselves through three different approaches: First, universities have to identify their basic missions and deemphasize activities not essential to those missions so that they can focus on their strengths; Second, universities have to pare down their internal bureaucracies, which will result in the reduction of the number of layers within their institutions. They can hire outside companies to provide services that they don't need to control directly, such as payroll, record keeping, data processing, legal services, maintenance services, transportation and security, among many others. Universities also have to increase financial incentives for excellence by rewarding employees who meet specific goals; Third, universities have to form alliances with each other and have to have an effective cooperation with industry to share expertise, cut costs and reduce risk. Research alliances with industry are particularly productive because they enable involved parties to combine disparate skills and share the ultimate rewards.

In recent years the discussion about whether the universities can encompass a third mission of economic development, in addition to research and teaching, has received more and more attention (Etzkowitz and Leydesdorff, 2000; Leydesdorff and Meyer, 2003; Mansfield and Lee, 1996; Khlaifat et al, 2006; Khlaifat and Qutob, 2010). The third mission cannot generate technological spillover without university-industry research cooperation (Martin and Scott, 2000; Siegel and Zervos, 2002).

University researchers choose to interact with industry for a diverse set of reasons (D'Este et al. 2005; Howell et al. 1998; Kurfess and Nagura, 1997; Meyer and Shmock, 1998, Khlaifat et. Al, 2006): industry pro-

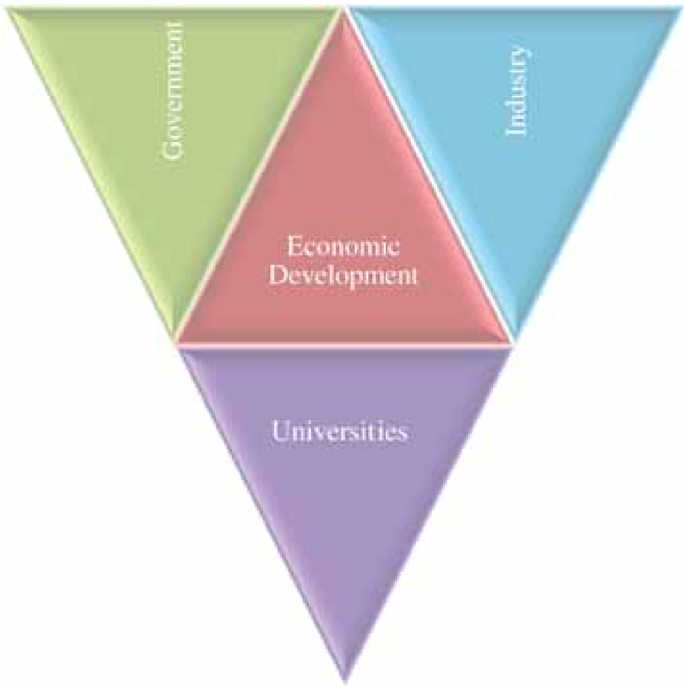


Figure 1: Country's Innovation Triangle.

vides a new source of revenue for university; industrially sponsored research provides faculty members and students with exposure to real world research problems and a chance to work on intellectually challenging research programs; industrial funding provides less "red tape" than government money; and, some government funds are available for applied research, based upon a joint effort between university and industry. On the other hand, several other reasons that motivate the industry to cooperate with universities have been identified by (Hill and Brash, 2004; Kurfess and Nagura, 1997) as: access to manpower, including well knowledgeable faculty members; access to basic and applied research results from which new products and processes may evolve; solutions to specific problems by professional expertise not available elsewhere; access to university facilities; conducting continuing education and training; and, obtaining prestige or enhancing the company's image and reputation.

The manuscript is organized as follows: Section 2 addresses the third mission that can be accomplished by universities and industries and its impact on the country's economic development. A description of effective university-industry cooperation in developing world is discussed in section 3. Section 4 presents different scenarios of planning for theplanning for the future. Section 5 is devoted to the case of Weatherford, where authors elaborate on the status of academia-industry relations and cooperation. Conclusions are presented in the last section.

2. UNIVERSITY–INDUSTRY COOPERATION AND ECONOMIC DEVELOPMENT

2.1 University-Industry-Relations

While it can be argued that cooperation between industry and academia would benefit both parties, such ventures have not always gone well, and are burdened by differences of pace, regulations and work environment. There must be a third party that gets involved in the cooperation business where the venture's objective is enhancing the country's economic development. Thus, the government-industry-university relations can be represented the best by a triangle (see Figure 1) that serves as the basis for any country's economic development strategy. The country's economic development must strategically position itself at the center of a government-industry-university triangle.

The triangle metaphor implies that there are close linkages between the three sectors and that these connections are instrumental in the country's economic development.

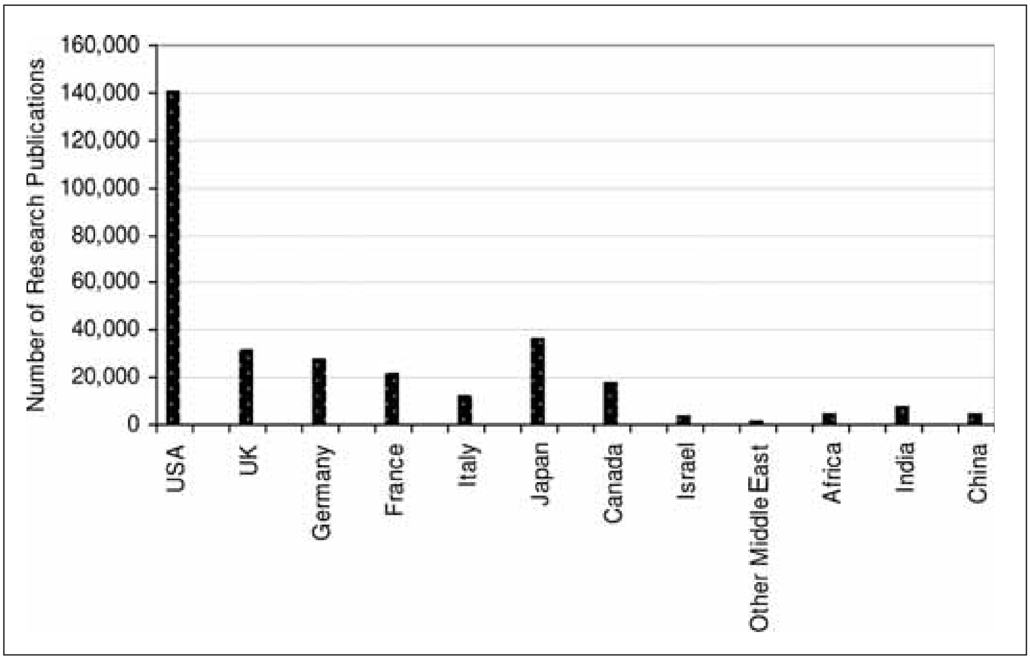


Figure 2: Number of Research Articles Published During 1993 for Different Countries.

2.2. Funding

Funding may be considered as the fuel for research and development (R&D). It normally comes from different sources: Self funding (University budget), government support, private business funding, and funds from private non-profit organizations. Fund providers normally expect return for their support. Universities benefit from the outcomes of research in improving accreditation and in attracting higher numbers of quality students and, to some extent, improve governmental support, since in some countries government subsidy for a certain university is partially tied to the achievements of that university in the field of R&D. It appears that the quantity and/or quality of the R&D outcomes are, in one way or another, linked to the availability of funds. The statistics of 1993 showed that over 33% of the worldwide research publications in internationally recognized peer reviewed journals come from the USA. The total US expenditure on R&D in 1994 was around $170 Billion (NSB report, 2004). Figure 2 shows such statistics of some other countries for comparison purposes (NSB report, 1996).

In the year 2000 US expenditure in support of R&D was above $260 Billion (NSB report, 2004), which is greater than the expenditure of the rest of the G7 countries together in the same field. Governmental share of this expenditure was 26%, private business 69%, and the rest is funded by private non-profit organizations. However, if the total amount expended on R&D is taken as a percentage of the national domestic product (NDP), it is found that US expenditure forms 2.67% of its NDP (UNESCO, 2005).

The importance of governmental support is well recognized in developed countries. Government percentage contribution in some countries is much more than that of the USA. For the purpose of comparison, Israel's R&D expenditure in 2003 was 5.11% of its NDP. Whereas, this figure is 0.19% for Kuwait and Egypt and only 0.063 for Tunisia, see Figure 3 (UNESCO, 2005). Credible statistics on funding of R&D in the rest of the Arab World countries are not available.

Despite the present share of the US government in support of R&D, there is a continuous demand for higher governmental contribution. Some American academicians and businessmen warned that, if federal funding is not raised, the US will lose its competitive edge to other countries, like India, Korea and China. Furthermore, there are worries that maintaining the standard of living and the leadership of the US will be challenged (Carlson, 2005).

Private business return for funding R&D takes the form of generating profit through improving existing products, services, work procedures, innovation etc. Funding from private nonprofit organizations in all countries is negligible when compared to governmental and private business funding.

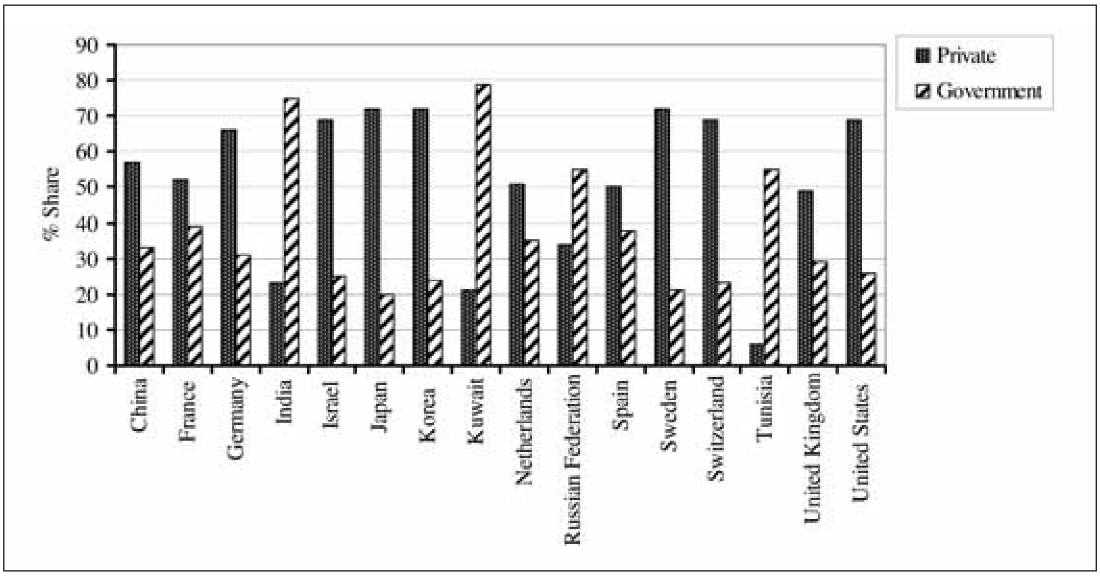


Figure 3: Government and Business Percentage Share of Expenditure on R&D in 2003.

2.3 Conflict of Interest

Development of Academia-Industry collaboration in the field of R&D is normally faced with the cultural differences between academic institutions and industries. These differences are mainly due to the different missions to be achieved by each. Most universities normally declare their mission as: Teaching; Research; and Outreach. In support of this mission, universities encourage the publication of research and development outcomes. In constrast, industry uses research and development outcomes to develop products, services, procedures etc., in order to generate profit. Usually, industry prefers to protect information from being disclosed such that they guard their competition interests (Severon, 2005). This matter has been of great concern to the American Association of University Professors (AAUP, 2006).

2.4. Talking the Same Language

It seems that there is still a certain degree of confusion among industrial businesses in some countries regarding the appreciation of what academia can offer in the field of R&D. Likewise, academia is not able to fully understand the R&D needs of industry (report on growing biomedical research in New Jersey, 2003). Some R&D work, although important to industry, may not be attractive to academia, mainly if the outcome of the work is not publishable in peer reviewed periodicals. In developed countries, like Japan for instance, the interest of academia has been improved by introducing a law to promote university-industry technology transfer, according to which 41 universities were authorized/accredited as Technology Licensing Organizations in 2004. The law is known as TLO Law. This achievement was only possible after a lot of discussions started as early as the 1960s (Takehiko, 2004). In other countries, such as India, a private sector firm launched a huge project to promote industry-academia collaboration through a number of initiatives (Infosys, 2004).

2.5. Creators or User of Technology

Most of the technology which industry in the developing countries is based on, is transferred from mother enterprises in the developed world. Factories and plants normally come as ready-made packages. Any development is normally suggested and carried out by the mother company, sometimes in its country of origin.

2.6. Personal Interests

The field engineers usually keep the promising research problems for themselves. They look forward to having an opportunity to go abroad for two or three years for training, in order to apply for graduate studies in their fields of specialization. They meet with academic advisors, who require only research work to graduate students. The data obtained are usually analyzed and a degree is offered. Records of the ministry of higher education /committee for accreditation of foreign degrees, in some Middle Eastern countries, show many of these cases.

On the academic side, research is looked at as a requirement for career development and promotion. Promotion is a necessity for the faculty member to get a tenure track and to continue getting annual salary increments. Thousands of faculty members in Middle Eastern countries have been promoted to associate or full professor ranks based on their research achievements, which, in many cases, are published in leading refereed and indexed international journals. Their publications need to be transformed from academic to applied format by a capable and highly qualified industrial R&D staff.

2.7. Research versus Teaching

Due to the funding difficulties facing universities, faculty members are heavily involved in teaching and so they find it difficult to have enough time to contact industrial companies for any means of cooperation. Legislation must be modified to allow faculty members to spend their sabbatical leaves in the industrial premises; moreover, fair salaries must be guaranteed. In this regard, industry can make use of the 1% of their gross income allocated for scientific research by law in some countries.

3. EFFECTIVE INDUSTRY-UNIVERSITY COOPERATION IN DEVELOPING WORLD

It must be admitted that industry cannot survive in the prevailing competitive environment without appreciating the need for R&D, which may not be completely met by in-house R&D, as discussed earlier. Universities and research institutions, by definition of their missions, have the proper resources, expertise and attitude for carrying out R&D activities. Such a demand-availability relationship should encourage industry-academia collaborations.

Although academia-industry collaboration in applied R&D is growing slowly, industry support to basic research is still far from being satisfactory. It is expected that continuing education programs and the development of active cooperative research programs will boost this support. Such programs can succeed with the help of proper joint research project preparation and implementation and if their terms of reference are S.M.A.R.T, which means:

- S: Simple terms and conditions understandable to both parties
- M: Measurable outcomes
- A: Applicable outcomes
- R: Reliable research results
- T: Time bond project duration

3.1. Joint Research Project Preparation

Before initiating a joint research project between a university and an industrial entity, each party must believe that its partner is willing to work jointly on grounds of mutual trust. This may be achieved by emphasizing the need to discuss openly two critical issues (recognition of parties' needs (3.1.1) and project duration (3.1.2)) to develop a strong foundation from which interactive research can be continued, these are:

3.1.1. Recognition of Parties' Needs

3.1.1.1. Business Needs and Expectations

The primary objective of the industrial sponsors is to find solutions for their needs. These needs are in the form of development and/or improvement of products, services, staff and procedures. Some of these needs can be met internally, by the entity staff. However the desire to conduct research that addresses some of these needs is in many cases beyond the internal capacity or interest of the entity, such needs are referred to specialists in the field. If this reference is made to a university through sponsoring a research project, the research outcomes must be submitted to the sponsors in the form of an applicable technical report, not in research paper format. Furthermore, the research team must be thoroughly involved in the implementation of the research outcomes. This involvement will boost the mutual understanding, trust and technology transfer.

3.1.1.2. Academia Expectation

Academicians show interest in industrial R&D activities only if they can benefit from the research outcomes. They normally weigh any proposed research work in terms of its potential to be a research topic for a graduate student, or, at least, the expected outcomes can be published in peer-reviewed periodicals. It must be made clear to the sponsor that the research content of the work must/will be published in the public domain. The publication of a thesis is essential for a graduate student to complete his/her degree, while archival journal publication is necessary for the career development of academicians.

This matter must be clarified before starting the project. Both parties must agree on what is publishable and what is not. This will eliminate a number of potential future unexpected conflicts. Without such an understanding and agreement at the outset of the research, significant difficulties can arise as such. For example; requesting significant changes in an almost completed thesis if it contains information the sponsor likes to keep as classified.

> Organizing workshops and conferences will further facilitate the exchange of experience and knowledge among staff from both sides (industry and academia).

3.1.2. Project Duration

In the dominant competition environment, time is a critical factor for success. Industrial sponsors prefer to have the research results as soon as possible. They always feel that it is a matter of a competitors' race. So, it is absolutely essential that the research project must be time-bound and its duration be mutually agreed in advance after estimating the quantity and quality of the research work involved. It is even better to divide this duration into phases, so that progress can be assessed at the end of each phase. Furthermore, the phase-approach helps universities in planning their research work and deciding who will be involved. For example, a one year project of a good quality research could form a suitable research topic for a MSc student, whereas a two- to three-year research project could be a suitable subject for a PhD thesis.

3.2. Facilitating Interaction between Academia and Industry

In order to accomplish the objectives stated earlier, the development of a partnership between academia and industry will enable them to participate through one or more of the following modes:

• **Working Together:** Academic supervisor(s) and graduate student(s) must maintain close and frequent contact with industrial sponsors. This is important to ensure that the project is addressing the questions posed by the sponsor as well as meeting the requirements for the universities. If it is possible, students and their advisors should spend some time at the industrial sponsor's facilities.

• **Research Staff Exchange:** Faculty members can spend their sabbaticals at industrial organizations in their field of expertise. Such involvement will facilitate mutual understanding of each other's strengths and challenges. Senior personnel from industry should be involved as expert members of committees that evaluate changes in curricula as well as new academic programs; this will ensure that the teaching programs and the curricula will meet the challenging needs of the industry. To provide a real-life exposure of the industrial world to the students, a vacation training program can be organized, where the program has to include industrial training of faculty and students with a built-in provision of incentives as well as for the appointment of adjunct faculty from the industry.

• **Workshops and Conferences:** Organizing workshops and conferences will further facilitate the exchange of experience and knowledge among staff from both sides (industry and academia). A series of workshops can be conducted to focus on the collaborated research projects or other concerns and exchange of state-of-the-art practices and knowledge.

• **Student Supervision**: To keep the project on schedule, it is important to closely supervise the students by both parties. This will help the industry to complete the project on time and will be coordinated with its other goals. Taking an extra term for the student to finish the thesis is acceptable from an academic point of view; this request is not possible for industry.

• **Technology Incubators:** A place where newly created firms are concentrated in a limited space. Its aim is to improve the chance of growth and rate of survival of these firms by providing them with a modular building with common facilities (phone, fax, computing facilities, Internet, etc.) as well as with managerial support and back-up services. The main emphasis is on local development and job creation. Setting up of technology incubation centers in close proximity to academic institutions could provide for fostering wholesome technology development. Many researchers are seeking opportunities to motivate scientific research with others who have the same research interests but distance, finance and other factors usually become major obstacles. Incubating the local and global distributed individuals and/or groups with research capabilities in a unique focused portal called incubator offers startups money, mentors and time to plan.

• **Science Parks:** Many names have been used for science parks, such as: technology parks, research parks, technopole, innovation centre, science city or science town, etc. Despite the slight differences that may exist among these different names, all terms describe an economic and technological development complex that aims to foster the development and application of high technology to industry. Research facilities, laboratories, business incubator, as well as training, business exchange and service facilities are located in the complex. It is formally linked, and usually located as close as possible, to a center of technological excellence, usually universities and/or research centers. Science parks are well known institutional instruments in science policy but, according to (Clark, 2003), it is not correct to view the science parks as rational models of technology transfer founded in economic theory. The idea behind having science parks is to locate new industrial sites close to universities in order to facilitate the application of science and technological innovation. According to (Yaslan, 2005), the science parks are characterized by:

• Promoting research and development by the universities in partnership with industry, assisting in the growth of new ventures, and promoting economic development.

• Facilitating the creation and growth of innovation-based companies through incubation and venturing.

• Stimulating and managing the flow of knowledge and technology between universities, R&D institutions, industrial companies and markets.

• Providing an environment where knowledge-based enterprises can develop close interactions with a particular centre of knowledge creation for their mutual benefit.

4. PLANNING FOR THE FUTURE

In order to have long-term relationships between industry and academia, both sides have to learn from their past experiences. The few following behaviors must be associated with effective cooperation:

• **Decision Making:** In effective cooperation decisions are discussed and agreed to by both sides.

• **Open Communication:** In effective industry-academia relations, both sides do whatever is needed to get the job done. As the project is completed, both sides should ensure that the project goals are being met. Otherwise, if the project is close to completion, both sides should plan the next phase of the project. Hiring the graduate student(s) who conducted the project always depends on the industrial sponsor being happy with the results. While communicating with the sponsor, the research faculty has to represent his/her students' research capabilities but also those of the entire university. Academia and industry in effective cooperation keep each other informed and they discuss each other's work and progress.

• **Appreciation of conflicts/differences:** Productive cooperative teams expect conflicts and disagreements. They have to openly discuss their differences and see them as means to improved decision making

• **Focus:** If both sides are willing to have effective cooperation, then they have to keep their ultimate goals and objectives in mind. If they fall behind, then either industry or academia or both run into trouble. Each side notices the cooperation error, but no one is willing to raise the issue or take the initiative and offer helpful solutions.

5. THE CASE OF WEATHERFORD OIL TOOL

Extensive efforts have been made during the last two decades to boost Weatherford-university collaboration. Many consider the major responsibility of such a cooperation lies on the academic side, while some others think it is in the Weatherford side. The authors believe it is a combination of several factors within the two

> "Universities and research institution, by definition of their missions, have the proper resources, expertise and attitude for carrying out R&D activities."

sides. Some of the manuscript authors, having worked in academia, had faced these cooperation gap issues for years.

Weatherford has different departments for research, development, and training. These departments do not limit their activities to training but they go beyond that and address different industrial challenges (e.g. Petroleum Consultants and Center of Excellence). Usually, these departments are headed by highly qualified engineers, geologists or chemists with PhD, MSc or BSc, degrees and their personnel have both the required qualifications and R&D experience. Therefore, R&D problems are usually formulated in a proper way to avoid any ambiguity between R&D needs and operational problems that require overnight solutions and not prolonged research.

The Weatherford MENA Well Engineering Centre of Excellence (WECOE) and Weatherford Petroleum Consultants (WPC) are working together to strengthen Weatherford's consultancy capabilities in conducting upstream studies in the MENA region and abroad. Cooperating with academic institutions lies within their mission. A number of good examples of WPC and WECOE cooperation with academia are discussed below:

• Teaching "Natural Gas Hydrates" graduate course at Norwegian Institute of Technology (NIT) from 1989 to 1998.

• Research and Development project carried by the best students studying petroleum engineering at Norwegian University of Science and Technology (NTNU) as part of their thesis and conducted at Weatherford during the last two semesters of their study. The advantage for the students was that they got an office in WFT premises, a top laptop with industry standard software components installed, and many senior WFT experts in the selected thesis topic to guide them in their work. Students worked with real field data and a real problem that gained interest from the industry (WFT), oil company (e.g. Statoil) and academia (NTNU). The most important benefit to WFT was that the students could work with different simulation software components and stay focused for an entire year without being distracted by any other business. This resulted in graduating professional engineers, of a high calibre, who could run advanced simulations. These engineers were acknowledged as simulation experts on a higher level than many seniors in operation companies. Operation and service companies became very interested in hiring these students after their graduation and offering them full-time positions. This generated a good revenue for WFT and operators who hired these young experts who are capable of simulating any IOR measure with Eclipse/Petrel/RMS++. This type of cooperation helped the university counterpart (students, professors and/or supervisors) to better understand industrial challenges and cope with the mindsets of people in the oil and gas industry. This successful model of cooperation was implemented between WFT and two other universities in

Bergen and Stavanger. During the last three years WFT had recruited the best students in each class. Nowadays, WFT is very well acknowledged by petroleum engineering students in Norway and is considered as a highly successful model of academia-oil industry cooperation. The number of student applications for such internships dramatically increased in 2010. (around 80% of the students studying petroleum engineering at NTNU).

• **Bridging the gap between laboratory scale and reservoir scale:** Weatherford Petroleum Consultants offer a university course on up-scaling the laboratory results to reservoir scale using SENDRA software in Norway. Due to the popularity and success of the first offered course, a decision was made to offer it on a regular basis in future semesters.

• **Adding Geomechanics Capability to Petrolog:** The desire to add the capability of performing geomechanical analysis, especially estimation of rock mechanical properties, with Weatherford log analysis software, Petrolog, was the main motivation to define a research and development project since long time ago. However, dedication of the related experts to commercial projects, in addition to the lack of sufficient budget and time, caused continuous delay in initiating the project. Finally, the decision was made to carry out the project through cooperation with academia. In order to proceed with this idea, several MSc students from Heriot-Watt University in petroleum engineering major were interviewed and one of them, whose competency matched the project requirements, was selected to carry out the project as an MSc project under the supervision of an WFT expert. The student was able to complete the project in two months with highly satisfactory results. He developed 62 algorithms which enabled Petrolog to calculate various rock mechanical properties (including dynamic and static elastic constants, rock strength, friction angle, and cohesion) for different rock types. Extensive quality assurance was carried out to ensure that the algorithms were consistent with the equations developed by various authors regarding their applicability conditions and geographical region restrictions. It is worth mentioning that the student was hired by Weatherford after completing his masters degree. As a result of this cooperation with a university, a delayed project was successfully completed in a short time with minimum involvement of WFT personnel and, more importantly, at a low cost. Furthermore, the university student and supervisor were also exposed to an industry related issue and could increase their knowledge and experience about this matter.

• The collaboration between Weatherford Well engineering Center of Excellence and Heriot-Watt University was extended to other areas of research, such as tight gas sand, underbalanced drilling and gas condensate reservoirs. Also, graduate students' MSc and PhD theses and faculty promotion applications are usually reviewed by WECOE staff for different universities worldwide.

Conclusion

From this paper we conclude that the best answer to the question, "What is the most effective method of cooperation between academia and industry?" is that it depends on the research project goal, student and his/her advisor, industry, and the university. But the next best answer is, "Mutual teaching between academia and industry". Industry and academia are two significantly different environments and must be integrated in a careful manner with sensitivity to the realities of both parties. Once the joint industry-university collaborative research projects ball starts rolling, the mutual interaction will provide many benefits for both parties that will be reflected in the country's industrial development. Successful cases of close cooperation between Oil and Gas Industry (Weatherford) and academia resulted in narrowing the gap between the two parties and better preparing the students for the job market.

References

American Association of University Professors, Statement on Corporate Funding of Academic Research, 2004 (www.aaup.org)

Carlson C., 2005. Industry, Academia Seek Federal R&D Funding. e-week, December 6, 2005 (www.eweek.com/article2/0,1895,1897076,00.asp)

Clark W., 2003. Science Parks: Theory and Background. International Journal of Technology Transfer and Commercialization 2, 150-178.

D'Este P., Nesta L. and Patel P., 2005. Analysis of University-Industry Research Collaborations in the UK: Preliminary Results of a Survey of University Researchers (Report). (www.sussex.ac.uk/spru/documents/deste_report.pdf)

Etzkowitz H. and Leydesdorff L., 2000. The Dynamics of Innovation; from National Systems and "Mode 2" to a Triple Helix of University-Industry-Government Relations. Research Policy 29, 109-123.

Hill D., Brash M., Campo A. and Doucette-Stamm L., 2004. Academia-Industry Collaboration: An Integral Element for Building "Omic" Resources. Genome Research, 14, 2010-2014.

Howell J., Nedevea M. and Georghiou L., 1998. Industry-Academia Links in the UK. Report to HEFCE, PREST, University of Manchester (www.hefce.ac.uk)

Infosys Launches Campus Connect, an Industry-Academia Partnership, Press Release, Bangalore, India, 2004 (www.infosys.com/media/campus_connect_final_jul26.pdf)

Khlaifat A. and Qutob, H., Bridging the Gap between the Oil & Gas Industry and Academia, The 2nd Saudi Meeting on Oil and Natural Gas Exploration and Production Technologies (OGEP 2010), Dammam, Saudi Arabia 18-20/12/2010.

Khlaifat A., Al-Khamis T. ,Teyfour W. , Abu Zaid M. , and Al-Ouran R., Effective Industry-Academia Cooperation. 4th International Forum on Engineering Education- IFEE2006, Integrating Teaching with Community Service, 25-27 April 2006, Sharjah, UAE

Kurfess T. and Nagurka M., 1997. Fostering Strong Interaction between Industry and Academia. American Society of Engineering Education Annual Conference, Session 0557.

Leydesdorff L. and Meyer M., 2003. The Triple Helix of University-Industry-Government Relations. Scientometrics 58, No. 2, 191-203.

Mansfield E. and Lee J., 1996. The Modern University: Contributor to Industrial Innovation and Recipient of Industrial R&D Support. Research Policy 25, 1047-1058.

Martin S. and Scott J., 2000. The Nature of Innovation Market Failure and the Design of Public Support for Private Innovation. Research Policy 29, 437-447.

Meyer F. and Shmock U., 1998. Science-Based Technologies: University-Industry Interactions in Four Fields. Research Policy 27, 835-851.

NSB Report (NSB 96-21), Science and Engineering Indicators 1996, National Science Foundation, USA, (1996) (http://www.nsf.gov/)

National Science Board, Science and Engineering Indicators 2004, Two volumes, Arlington, VA: National Science Foundation (Volume 1, NSB 04-1, 2004; Volume 2, NSB 04-1A, 2004) (http://www.nsf.gov/)

Report on Growing Biomedical Research in New Jersey: The Garden State. A Forum for Thought-Leaders from Industry, Academia and Government, Doubletree Conference Center, Somerset, New Jersey, March 10, 2003 (www.njabr.org/pdfs/growing_report.pdf)

Severon J., 2005. Models of University-Industry Cooperation, Journal of Industry-Academic-Government Collaboration 1, No. 2, 99-106.

Siegel D. and Zervos V., 2002. Strategic Research Partnership and Economic Performance: Empirical Issues, Science and Public Policy 29, No. 5, 331-343.

Takehiko Y., Encouraging Greater Government-Academia Collaboration, Research Institute of Economy, Trade and Industry, 2004 (www.rieti.go.jp/en/index.html)

Yaslan N., 2005. Science Parks, Science Analysis and Policies Division, Science Sector, UNESCO (www.unesco.org/pao/s-parks/s-parks.htm)

UNESCO institute of statistics, March 2005.

www.uis.unesco.org/TEMPLATE/html/Exceltables/science/R&DTables.xls

Formation Damage Laboratory Testing – Cost Effective Risk Reduction to Maximise Recovery

By Clive Cornwall and Bassem Yousef, Corex.

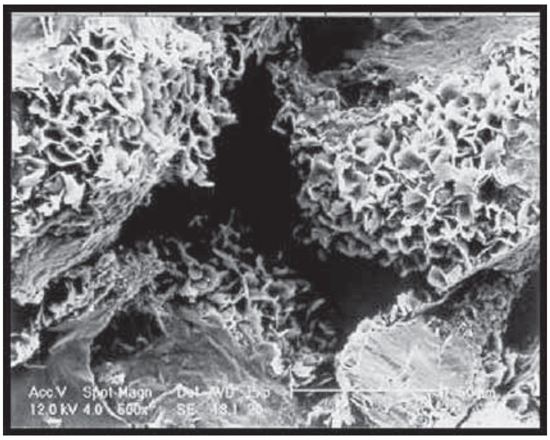
In recent years the oil and gas industry has seen rising costs associated with various operational activities such as drilling, completing and treating wells. However, economic pressure is not the only challenge within the market, environmental responsibility and the trend towards deeper drilling has led to many operators taking a total quality management approach to enable successful well operations. Any additional information that can be obtained to assist with operational decisions is much welcomed. Laboratory testing is viewed as a cost effective and low risk route to gather vital information in understanding the areas which may create risk during the life of a well. Appropriately structured testing programs including advanced interpretation techniques can have short, medium and long term benefits. This article will set out the main arguments to undertake laboratory assessments, and discuss some of the areas where the results can be particularly valuable.

Mechanisms which have an unfavourable economic impact can occur at any point during the life cycle of the filed such as drilling, completion, production, injection, treatment, and stimulation. These mechanisms which are termed as "Formation Damage" can manifest themselves in various ways, but fundamentally involve interactions between the reservoir (rock and fluids) and the introduced operational fluids and hardware. Drilling mud infiltration, poor mud-cake clean-up, fluid retention, fines mobilisation and pore blockage, fluid incompatibility and precipitation, emulsions/ sludges, removal of cement, clay swelling, and sanding are all examples of mechanisms which can have an impact on productivity or injectivity.

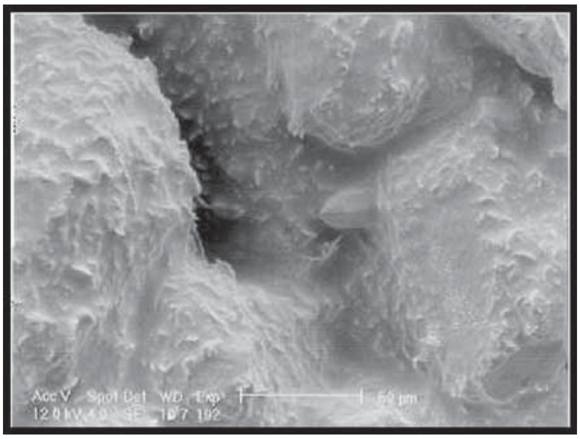
Laboratory testing can be performed to identify these damaging mechanisms, and with the correct interpretation useful recommendations can be made on ways of avoiding or removing them. The testing therefore becomes part of the quality management "Plan, Do, Study, Act" cycle: laboratory testing checks for problems or mechanisms, defines the options available for avoidance, tests the solutions for effectiveness, and provides feedback to aid in implementation. In terms of risk, the greater level of understanding can not only reduce risk, but add value to the planning process, as it is significantly cheaper to experiment in the laboratory than the field. A key aspect of laboratory testing is that it is direct measurement, whereas models are indirect or derived measurements; test data can therefore be used as inputs which consequently supplement or improve models. In addition, independent testing is key in the "calibration" of vendor recommendations on fluids and hardware, allowing comparison across vendors, fields, and operators.

Testing to examine wellbore operations typically consists of preparing core samples to representative wellbore conditions, and simulating the operational sequences under consideration. Care must be taken throughout the process, to avoid any impact of the equipment or procedures on the outcome of testing. Equipment must not corrode, even when flowing strong acid under HPHT conditions; the techniques used to prepare the samples (cutting, cleaning, drying, saturation, permeability measurement) must not create artefacts; and the conditions and sequence tested must be representative in terms of the fluids and hardware being considered, exposure times, temperatures, pressures, overbalances and underbalances. Expert consultants assist with the test design (e.g. mud cake development, horizontal versus vertical core holder orientation, wellbore operational sequence to be evaluated) so that the required objectives are met and also to ensure that test results are not misleading. The output data from testing typically includes permeability measurements, filtrate loss volumes, production/injection plots, and sample photographs, which are all used in aiding conclusions.

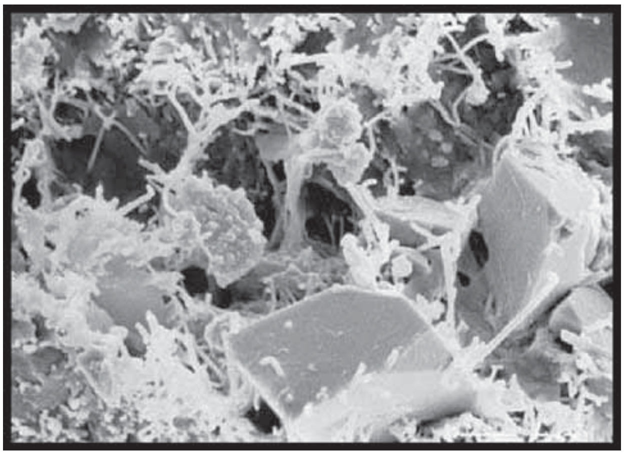
After having performed a well-designed and executed test it is, however, just as (if not more) important to understand the results fully. Relying upon permeability alone creates a high risk, as in short core samples it is common for both pore restricting (e.g. drilling



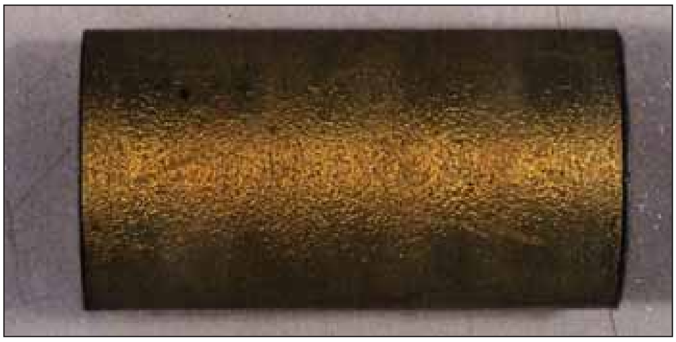
Before Test Dry SEM image



After Test Cryogenic SEM image



Damaged illite from unsuitable cleaning technique



24-carat gold film prevents gas leaking from the core under hydrothermal conditions.

mud infiltration, scale precipitation, fluid retention) and pore-enlarging (e.g. clay fines removal, cement removal, saturation change) mechanisms to be seen. The combination of these can lead to increases, decreases, or no overall change in permeability, even though there are a number of mechanisms which could potentially cause problems in the field. For example, in short core samples it is relatively easy to mobilise and remove high surface area clays, which will increase permeability, where in the field increased transit distance and concentration as the particles move towards a smaller volume in the near-wellbore area can lead to significant reduction in pore space. To reduce risk and increase understanding of results, interpretative geological analysis including scanning electron microscopy (SEM), x-ray diffraction (XRD), thin section, and innovative techniques such as cryogenic SEM are all used to examine samples before and after testing to understand the impact of the sequence tested. These short core flood tests are informative and generate the inputs required to enable up-scaling for lateral simulation.

Laboratory testing is performed by operators worldwide to help them in decision-making during exploration, development, treatment/workover, production, injection, and at any other point in the lifetime of a well where there is an opportunity to avoid or remediate damaging mechanisms. Operators should consider testing as a vital part of the "best practice" in selecting fluids and hardware, and as such the many types of tests being performed reflect upon the wide range of operations being performed worldwide, with each test being customised to the operator's specific needs. Some areas where there have been recent innovations in laboratory testing at Corex include:

Heavy oil

With the current (and future) emphasis on non-conventional reserves, traditional testing techniques can struggle to adequately represent heavy oil reservoirs. Specialist sample preparation techniques have allowed the core samples to be prepared in a manner that does not impact on their integrity, for example avoiding removal of oil cement which can create unconsolidated and unrepresentative samples. Improvements and innovations in geological techniques have also allowed for visualisation of pore-lining and pore-filling fluids without impacting on the integrity of the samples.

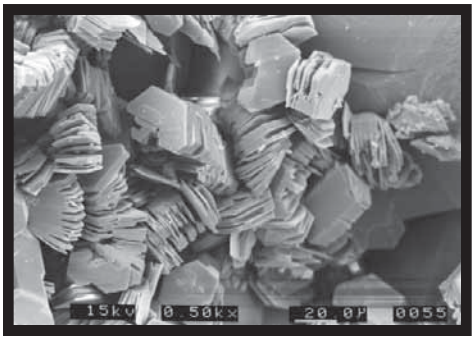
HPHT

High pressure, high temperature (HPHT) reservoirs, particularly tight gas, have also historically proved challenging to perform representative testing upon. Useful testing is especially vital in these fields, as any damaging mechanism can have a significant impact on permeability, and therefore the economic viability of a field. Identifying and avoiding damage before it occurs is essential in HPHT testing, and the testing needs to be performed at meaningful temperatures and pressures; the main innovation here is the design of equipment at Corex that allows wellbore operational testing to be carried out at temperatures of over 200°C including (if required) humidification of gas at reservoir temperature.

SRA of injection operations and production drawdown operations

Scale Risk Assessment (SRA) which can range from prediction to squeeze design, Corex independently evaluate scale formation and inhibitor selection. Utilising state of the art laboratory equipment and

Corex's advanced HPHT Scale Rig performs many tests to establish Scale Risk Assessment (SRA).



Abundance of pore filling and grain coating Kaolinite clay booklets.

methodologies in combination with expert post test geological sample evaluation, scale inhibitor chemicals are evaluated for formation damage mechanisms. Inhibition life time is measured in the laboratory and optimised for field squeeze application

High-rate gas

On the other end of the spectrum to tight gas is high-rate gas, which has also posed problems in the past in terms of accurate control and measurement of rate over a large range of pressures. Corex have recently designed equipment that refines this to a level never before seen in reservoir conditions testing

Assessment for Halite rich reservoirs and well operations

Specialist Cryogenic SEM analysis techniques and preparation as well as integration with modelling criteria will assist in the assessment of well operations for Halite rich injection or production intervals. Full wellbore fluid sequences are simulated under reservoir conditions (pressure and temperature) to closely mimic those of the reservoir in question, thus accurate representation. Damage mechanisms (such as precipitation or dissolution) can be identified which will specifically address the changes in equilibrium experienced with Halite rich intervals.

Conclusion

To conclude, formation damage testing is highly sensitive to the techniques and equipment used. It is vital that each test meets its objectives, so having flexibility in procedures could be viewed as more meaningful than having a "standard" procedure that provides comparable results that do not necessarily relate to field conditions. It is relatively easy to perform low-specification formation damage testing in an unrepresentative way, but more challenging to mimic wellbore conditions closely. Formation damage test results are known to vary from laboratory to laboratory based upon equipment, procedures, and parameters used, so it is important to consider the capability of the laboratory when interpreting results or putting them into context.

These examples of "challenging" scenarios help demonstrate that, if the tests and equipment are properly designed and implemented, and results are fully interpreted, independent laboratory testing can significantly reduce risk in operational decisions.

Design, Analysis, and Diagnostics for Passive Inflow Control Devices with Openhole Packer Completions

By Gonzalo A. Garcia, SPE, Paolo Gaviolo, SPE, and Juan Carlos Serrano, Baker Hughes Incorporated

This paper was prepared for presentation at the 2010 Offshore Technology Conference held in Houston, Texas, USA, 3–6 May 2010.

Abstract

More than 12 years of field experience using reservoir-optimized completions, including passive inflow control devices and openhole packers in sandstone and fractured carbonate reservoirs, has led to the accumulation of best practices, guidelines, and rules of thumb to design, analyze, and diagnose these types of completions. This paper summarizes the most important issues to consider in each phase of the design and analysis of these completions.

Important design and diagnostic considerations have been generated in order to design the passive inflow control device under different fluid properties, reservoir uncertainties, and optimum operational considerations that allow for equalization of flow along the entire length of the horizontal section. These best practices came from simulation studies and, more importantly, from extensive worldwide run history and lessons learned.

No matter what the reservoir type is, the use of openhole packers for horizontal section compartmentalization offers a benefit in terms of inflow and annulus flow control. Therefore, it is important to determine the optimum number of isolation packers and the placement of packers to be used in each application. An extremely important role of compartmentalization is the ability to control gas and/or water after breakthrough occurs in highly fractured carbonates. This has been proven from analyzing a significant amount of production logs post installation.

Once the completion is in place, it is important to determine its effectiveness in order to establish potential optimization actions. Therefore, the analysis of pre- and post-job data available provides valuable information to determine the optimum operation conditions. The estimation of net benefit for this technology plays an important role and it can be determined before or after its

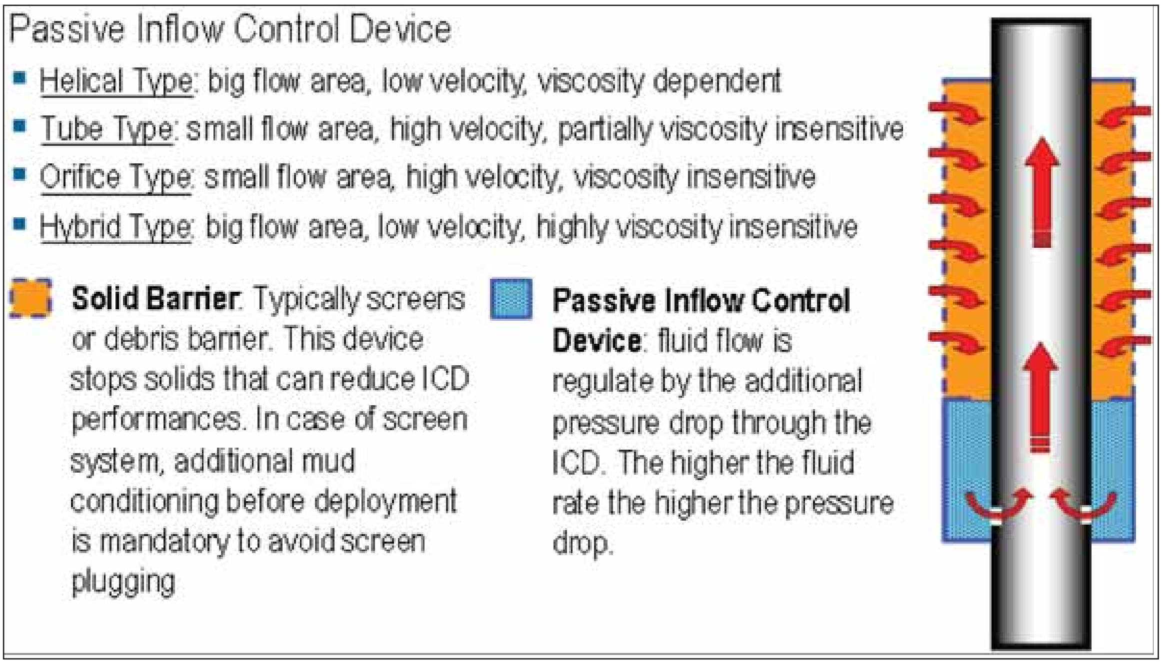


Figure 1. Categories of Passive Inflow Control Devices and general characteristics.

installation. Important guidelines will be presented to quantify the added value of this technology.

Introduction

Several papers have been written so far to explain the value added by PICD in horizontal wells[5,9,13]; as well as papers explaining potential PICD applications (for instance: producer & injector, oil & gas, sandstone and carbonate, single lateral or multilaterals) but not describing the design, analysis and diagnostic of this technology. The design phase plays an important role in order to obtain the benefit of this technology. The wrong selection of the right PICD for a particular application can lead to results not satisfactory et al.

No matter if the PICD completion is gravel pack or open annulus, the design is highly important in obtaining optimum flow velocity, flow rate, influx equalization and therefore better water control and optimum oil recovery. The main key behind the PICD design is determining the optimum amount of PICD joints, the flow resistance rating (geometry), the location, and the optimum number of compartments as well as packer type.

In the past those results were obtained by trial and error, field experience or using steady state simulators. However, most recently numerical simulators (transient models) have been used that include the well completion description to establish the optimum well completion equipment and obtain the best horizontal well performance.

It is also important to mention that just two years ago the PICD flow performance characteristics for different PICD types was fully described[6]. It helped to understand the best features of the PICD existent in the market and came up with a hybrid PICD design that combines such features as less fluid viscosity dependence (for heavy oil application), high flow area (no plugging), minimum flow velocity (no erosion), adjustability (one geometry design fits almost all applications), more flow resistance at the water breakthrough.

Once the PICD flow performance was included a numerical simulator was able to evaluate application as PICD in gas wells, gas condensate wells, SAGD, water injector, multilaterals, and other described by Garcia G. et al[5]. All those applications were designed to evaluate in each case the amount of fluid traveling in the annulus space between hole size and OD screen and therefore using the optimum packer numbers in order to minimize the annulus flow velocity (lineal flow) and transforming it into radial flow.

This paper describes the PICD design process step by step supported with plots obtained by field experience as well as with numerical simulations. Once the equipment is installed it will be necessary to evaluate if it is performing as expected or if it is possible to optimize production; current diagnostic technique is described as well as remediation options to be implemented in those cases where the PICD was not selected as the primary solution.

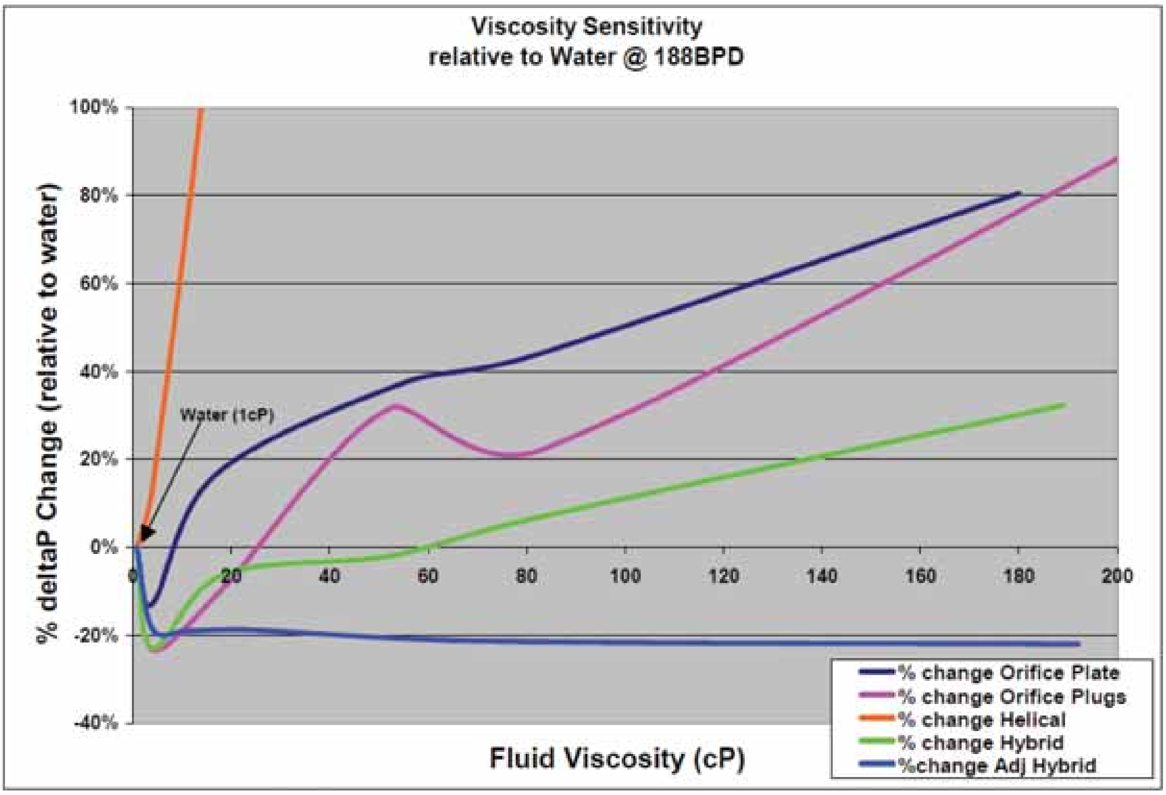


Figure 2. Full scale comparative tests results: viscosity dependence of different types of ICDs.

Design of Passive Inflow Control Device Systems

The design of a PICD system has to take into account the appropiate selection of the PICD type, the selection of the required Solid Control Barrier, the compartmentalization of the system, the PICD pressure drop rating selection, and the optimum number of PICDs. All these considerations are critical to guarantee a long term succesful application.

Selection of the Passive Inflow Control Device

The Passive Inflow Control Devices available on the market can be grouped into four main types: helical channel type, orifice type, tube type and hybrid type.

Generally speaking, the PICD with helical channels and the hybrid type present a bigger flow area than the orifice type. Therefore, the four types can be grouped into two categories: low velocity PICDs (helical and hybrid) and high velocity PICDs (tube and orifice). Figure 1 summarizes the four types' main characteristics and general features of the different PICDs available on the market.

Planning and designing for a big flow area and a low flow velocity (helical type) is always the safest option. and it should always be pursued for this kind of completion. In fact, it will guarantee that the tool will always operate below the erosional velocity limit (increasing tool longevity) and will minimize plugging issues. The only sound reason to justify a small area, high velocity design (orifice type), would be in the case of applications for very high oil viscosity which could result in an unwanted and excessive pressure drop through the PICDs, as this type of PICD is more insensitive to viscosity than the helical and tube types. Recently, two new hybrid designs were introduced to the market to provide the highest insensitivity to viscosity, and eliminate the need for smaller flow area ICDs. These hybrid PICDs improve the performance and thereby minimize the risks associated with the high velocity PICD, especially for high viscosity applications[1].

Moreover, from a recent comparative full scale flow testing[6] (see Figure 2), it resulted that orifice type PICDs can be very dependent on viscosity and the pressure drop can double on a 1 to 200 cp viscosity range. In fact, an orifice PICD is not an ideal orifice so its flow behavior is not simply dependent on the Bernoulli equation, which is independent from viscosity. It has been found that the discharge coefficient, responsible for the pressure drop behavior of an orifice, is not constant but changes with

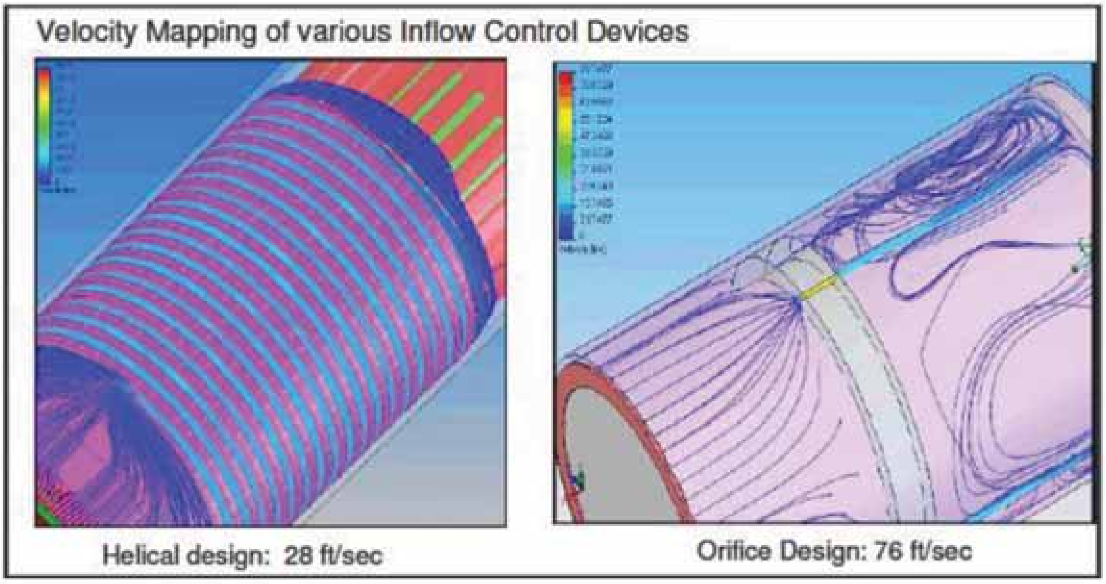


Figure 3. Velocity mapping through different ICDs under identical flow test conditions.

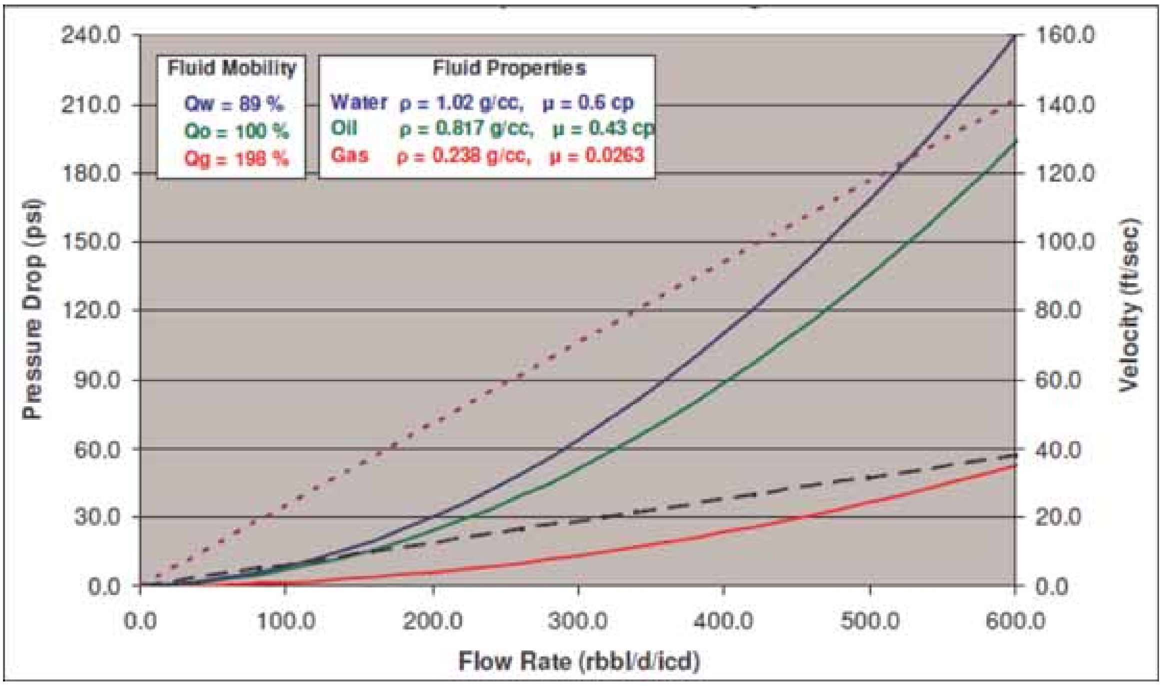


Figure 4. Flow performance of the ICD helical channel type.

viscosity. One of the new hybrid type ICDs showed a much lower dependency on viscosity, with an increase of pressure drop of only 30-35% over a range of 1 to 200 cp. The latest hybrid ICD that has come onto the market shows an even lower viscosity dependence and actually the pressure drop for any viscosity above 1 cp is 25-30% lower than the pressure drop given to water, making this ICD the only one able to selectively choke water more than oil (Figure 2).

As seen in Figure 3, the velocity inside a PICD helical type is, by design, always low (between 20-30 ft/s), compared to an orifice type of PICD, where the velocity typically exceeds 70-80 ft/s. This becomes especially important from a long-term point of view, where a high-velocity can accelerate the rate of erosion and shorten the operational life of most equipment. Moreover, if the PICD gets eroded and enlarged, the pressure drop given to the fluid will change significantly. For example, a

5 mm orifice that becomes 6 mm in diameter by erosion would lose 50% of its flow resistance rating, applying to the fluid, the pressure drop would be half compared to the original design. Therefore, the operational conditions and equalization capability of the completion would change completely.

Figure 4 shows an example of the flow characteristic curve for a PICD with helical channel design. The curves are based on the PICD geometry and the fluid characteristics of typical light oil from a Middle East carbonate field.

Under these conditions, low viscosity fluid, all types of PICDs, would have a very similar behavior in terms of pressure drop vs. flow rate, as previously shown in Figure 2. The difference will be in the velocity of the fluid through the ICD itself. The two dotted lines represent the velocity of the fluid inside the helical PICD and inside an equivalent (in order to have the same equalization capability) orifice type PICD. For any given rate, the velocity inside the orifice type is about three and a half times greater than inside the helical channel type.

From Figure 4 (fluid mobility table) it can be seen how the gas mobility inside the PICD is only two times the mobility of the oil. In the reservoir, or even worse, in the wellbore, the typical mobility ratio between oil and gas is usually much higher. This explains the ability of the helical channel design to control free gas, enabling higher oil production.

Figure 5. An example of debris barrier from an ICD for consolidated formations.

Another important benefit of the low-velocity, large flow area PICDs is the plugging resistance. Plugging is a potential problem that could occur any time during the life of a well, compromising production and greatly reducing the effective PI of the well. For this reason, it is very important to initially choose the appropriate completion that is suitable to last in the hole for the entire life of the well, thereby avoiding expensive failures and consequently more expensive workovers.

Solid Control Barrier Selection.

As anticipated in the previous paragraph, the type of solid control device depends on the formation type where the PICD has to be run. The two main categories are: PICDs for sandstone formations, where the solid barrier is a conventional sand control screen, and PICDs for carbonate or consolidated formations, where the solid barrier is only a small coarse debris barrier. In some PICD models available on the market, the solid control barrier can even be absent. In the next sections, the importance of these solid control devices and the main selection criteria will be discussed.

Sandstone formations applications

For sandstone applications the PICD should be equipped with a sand control screen. The screen is mounted on unperforated base pipe and attached at one end with the ICD unit in order to force the fluid coming from the reservoir to flow through the screen and then travel in the annulus between the screen and the base pipe and finally enter into the ICD module, where the desired pressure drop will be applied.

For the screen selection criteria, all the standard sand control industry best practices apply. It is not the purpose of this paper to present them. It is worth mentioning that now all type of screens are available for combination with ICD, including premium mesh screens, standard wire wrap screens, and wrap on pipe screens. The selection will be based on the Operator and Screen provider criteria, upon sandstone formation analysis and evaluation.

In case a stand-alone application is not recommended, PICD with sand control screen can also be gravel packed. A few applications have been successfully deployed in West Africa with very good operational and production results[10].

Carbonate or consolidated formations applications

For carbonate or consolidated formation applications, typically the sand control screen is replaced by a coarser and shorter debris barrier (Figure 5), mounted on the unit in order to protect the PICD module. This element is sometimes overlooked, but it is essential for the system to work properly.

The purpose of the barrier is to provide protection for the PICD module by stopping any undesired coarse debris coming from the formation, while allowing finer particles and cuttings still present in the hole to pass through freely.

The lack of any barrier will increase the risk of plugging, especially in cases where the open hole section was drilled with drilling fluid losses, and was not properly cleaned out. This is especially important if the PICD type is an orifice; in this case the barrier is critical to prevent plugging of the sometimes extremely small flow area.

The barrier must be correctly sized; in a carbonate formation a conventional sand screen is not needed, as it can be risky. The screen could be plugged while running in hole, especially as, as mentioned before, sometimes the wellbore is not conditioned due to loss of circulation while drilling. So the barrier has to be forgiving and allow a certain amount of solids to go through without plugging the barrier or PICD. Large area PICDs with coarse debris barriers have been run in more than 230 wells in carbonate formations in the Middle East and never reported any plugging issues.

Design of the Compartmentalization

The Role of Open Hole Packers in PICD Completions. OH packers are run between sections of PICD in order to hydraulically separate producing intervals with different characteristics in porosity, permeability, or number and size of fractures. The systems also divide producing intervals from zones where it is not desirable to produce, i.e. fractures/faults zones with risk of early water/gas breaktrough. The design of the assembly is customized in order to meet the reservoir engineering needs. The number and the position of the OH packers are discussed in the next paragraphs. To date, about 200 of these completions have been run in carbonate reservoirs in the Middle East. The hook-up for different PICD and OH packer completion types are presented in Figure 6.

Types of OH Packers for ICD completions. There are many types of OH Isolation Packers available. Each packer has its own unique features and benefits as well as its limitations. Hence, it is important to choose the appropriate packer for a specific application. The following factors (not exhaustive) should be considered in determining the appropriate packer.

- Deployment complexity
- Deployment time
- Immediate seal required (only applicable to Reactive Swell)
- Pressure differential rating of the end result
- Ability to accommodate big variations in hole size.
- Application for the packer (block gas migration, water flow, provide zone isolation, stage cement job, isolate loss circulation zone, protect sensitive zone, plug and abandon, etc.)
- Packer's ability to comply with well program and properties
- Max OD while running in hole
- Formation type (shale, sand, carbonate, etc...)
- Well trajectory and well data (mud weight, open hole, inclination, dog leg, etc.)
- Cement slurry information if cement inflated ECP is chosen.

For PICD applications two categories of OH packers are mostly used:

- Swelling Elastomer Packers. This packer has been designed to work in either oil or water to provide an an-

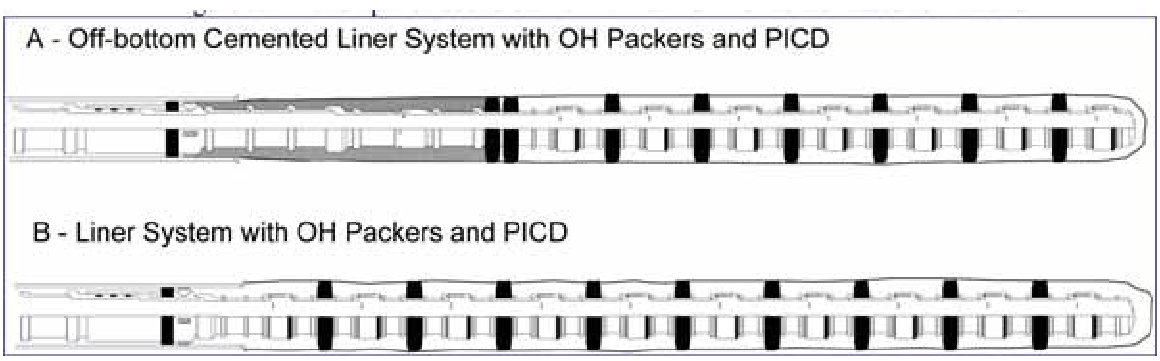


Figure 6. Open Hole Packers Applications in Different PICD Completions

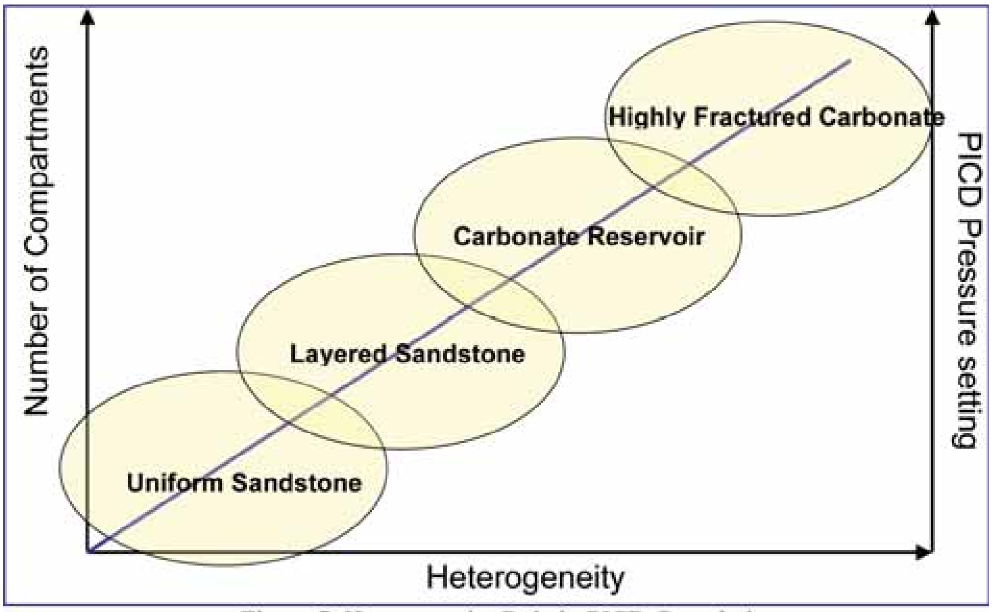


Figure 7. Heterogeneity Role in PICD Completions.

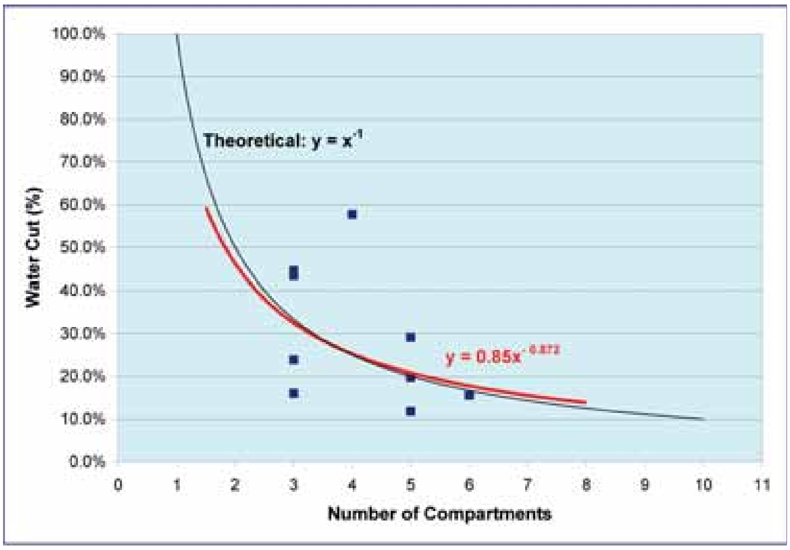


Figure 8. Effect of Compartmentalization in Water Control.

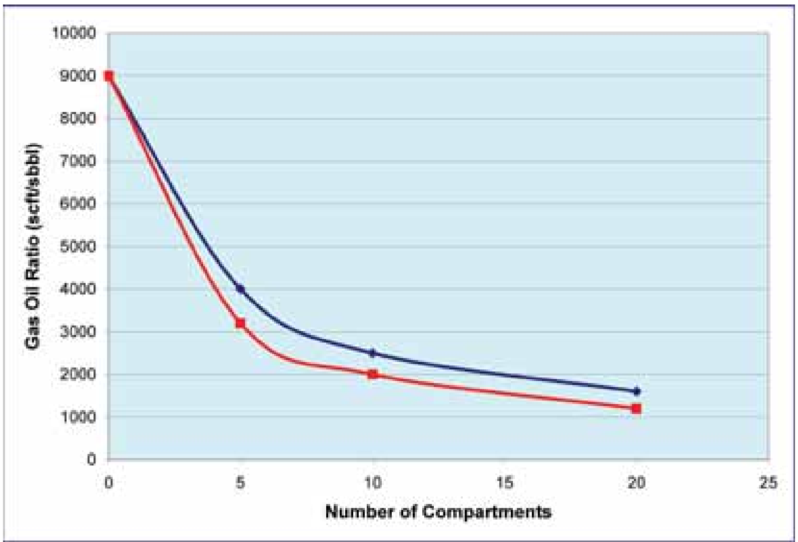


Figure 9. Effect of Compartmentalization in Gas Control.

nular seal in oil producers and water injectors. Elastomers reacting with oil-based fluids can initiate the swell reaction in concentrations as little as 3% oil, ensuring the element will set when deployed. As for the water-swelling compound, the rate of reaction or swelling is a function of temperature and concentration of salts. The polymer will not react in a pure oil-based fluid but will begin swelling in low water-cut fluids. There are a few things that are important to know about the water-swelling elastomer and the salt type present. Monovalent salts such as NaCl, KCl and formates are reasonably good at providing enough 'free water' for the element to function (up to about 20% by wt). However, divalent salts such as $CaCl_2$ and $CaBr_2$ will inhibit the swelling of the element in relatively lower concentrations (>5% by wt). When a scenario involves high salt concentrations and/or divalent salts, it is recommended to displace the packer area with a fresh water based fluid or water cut hydrocarbon production.

• Mechanical Non-Inflatable Packers. This type of packer has an elastomeric element with a composite structure which is set mechanically by allowing wellbore hydrostatic pressure or applied hydraulic pressure to flood an atmospheric chamber and to apply setting force to the noninflatable element. The element is then mechanically locked in place via a body lock ring. Additional setting force can be attained by applying additional pressure by selective means or by applying pressure to the entire casing string if applicable.

As previously indicated, many different aspects have to be taken into account for packer selection, but there are some general considerations that we can summarize here. The long swelling elastomer packers have better differential pressure rating than the short swelling constrictor, while the mechanical packers can accommodate bigger hole variations. In view of the simplicity in the deployment of the swelling packers they usually will be the first choice if the open hole, swell time and pressure rating allow it. For bigger open holes and uncertain wellbore condition (due to missing caliper log) or for immediate sealing needs the mechanical packer will be the preferred choice.

The Importance of Compartmentalization in PICD Completions. When designing a PICD system, it is generally accepted that the PICD pressure setting and the number of compartments should increase when the degree of heterogeneity along the wellbore increases in order to optimize equalization (Figure 7).

This design concept is justified as, in an OH completion, each feature of heterogeneity to be controlled should be trapped in a short compartment and produced through a reduced number of PICDs. This concept is always true, except in the case of a perfectly collapsed annulus condition; this condition, though, can never occur in a carbonate formation and rarely happens in a sandstone formation. The annulus as an open area will be the path of least resistance for the fluid after entering the wellbore from the reservoir. So the PICD completion is creating a resistance to the fluid flow (pressure drop) that, even if minimal, is still enough to divert the flow in all directions in the annulus before entering the completion. If severe heterogeneities are present, the reservoir-to-wellbore flow will be dominated by those heterogeneities, minimizing the benefits of a PICD completion.

As mentioned before, the number of compartments is highly related with the heterogeneities of the reservoir properties, i.e. permeability. In order to minimize the uncertanties of productivity distribution along the wellbore, a recommended approach is to deploy a so-called even distribution of PICD and OH packers with a maximum compartmentalization, only one PICD joint per compartment. In this case, since all the compartments are equal, the risk of placing a high number of PICDs in a high productivity section, or vice versa, is minimized. Another intrinsic benefit of this approach is to minimize the adverse influx performance of a potential unsuccessful deployment of the system, system placed off the target depth. In both cases, the self-adjustable capability of the PICDs will take care of the differences in productivity of the different zones, and will effectively equalize heterogeneities. This approach has been extensively used, especially in the Middle East, with substantial benefits.

Moreover, this phenomenon cannot be detected by running a production log tool (PLT), which most likely will show a perfect inflow profile in an ICD completion; in fact, what is seen in a PLT is the oil influx from the annulus to the completion, and events at the formation face are masked by the completion itself. Interestingly, a completion with no packers at all will show a better profile in a PLT due to the behavior explained above: the fluid enters the wellbore and flows freely in the annulus before entering the completion, so the equalization will happen only between annulus and completion, leaving the high productivity index (PI) zones free to dominate production in the annulus. For these reasons, a steady state simulation has be to be performed to show the importance of compartments in case of dry oil production, as the production logs, currently in use to assess this kind of completion, will not yield this information.

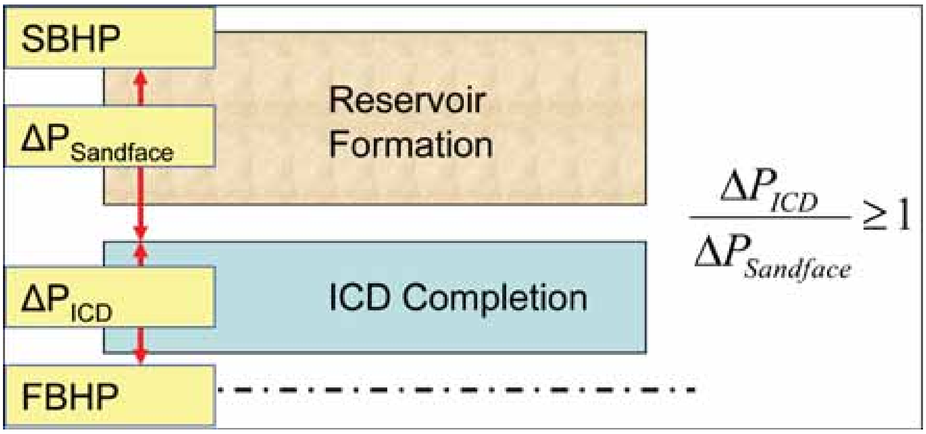


Figure 10. OH Pressure distribution with ICD completion.

Water and Gas Control

The scenario described above changes when water or free gas starts arriving into the wellbore. At this point, assuming that these undesired fluids are produced by some high PI portion of the pay, and not from the entire pay, the domination of high PI features will be detected by looking to the production data. In this case, the presence and number of compartments will play a critical role.

Generally speaking, increasing the number of compartments results in a better control of both water and free gas production. This performance has been extensively proven by both simulation and field results. In Figure 8 the effect the number of compartments has on controlling water is shown.

The data shown are from a carbonate field in the Middle East. The water cut of each well experiencing water production in a certain area after at least one year of production has been plotted against the number of compartments in the well. The derived trend line approaches the theoretical expected behavior of an inversely proportional relationship between water cut and number of zones. Based upon this behavior and based upon the suspected mechanism of water production in a well (fractures, coning, fingering, etc.) the design of the optimum number of compartments can be established.

For free gas control, the number of compartments required to reach an optimum control is intuitively higher than in the water case due to higher gas mobility, as shown in Figure 9. The data shown are obtained by simulation of a well in a North African field. The assumption is that in a 1,500-ft wellbore, a 50-ft section is gassed out completely, and the annulus is fully open. In a scenario with ICD but no packers, the gas greatly dominates in the annulus due to the favorable mobility ratio. The gas oil ratio (GOR) rapidly decreases by adding compartments and trapping the gas-producing zone into smaller and smaller sections. All this is assuming that the position of the gas producing section is not known, and the compartments are all the same in length, including the same number of ICD units.

The two lines represent two different ICD settings, the red being a double pressure drop through the ICD for the same rate compared to the blue. As it can be appreciated from Figure 8 there is a GOR reduction by using different type of PICD, but the GOR reduction effect is made much stronger by adding compartments than by increasing the pressure drop into the ICD.

Flow Resistance Rating and Number of PICD.

After the type of PICD has been selected, the flow resistance rating (FRR) of the PICD and the number of units to be used have to be defined. During this stage, some important factors have to be considered:

• Reservoir and well characteristics. The most critical well and reservoir data needed to design the ICD completion are: fluid PVT data, fluid density, reservoir static pressure, expected PI, permeability profile or expected permeability variation, well trajectory, fluid saturation, and relative permeability curves.
• Minimum target rate (total liquid rate). It is very important to define the minimum liquid target rate of the

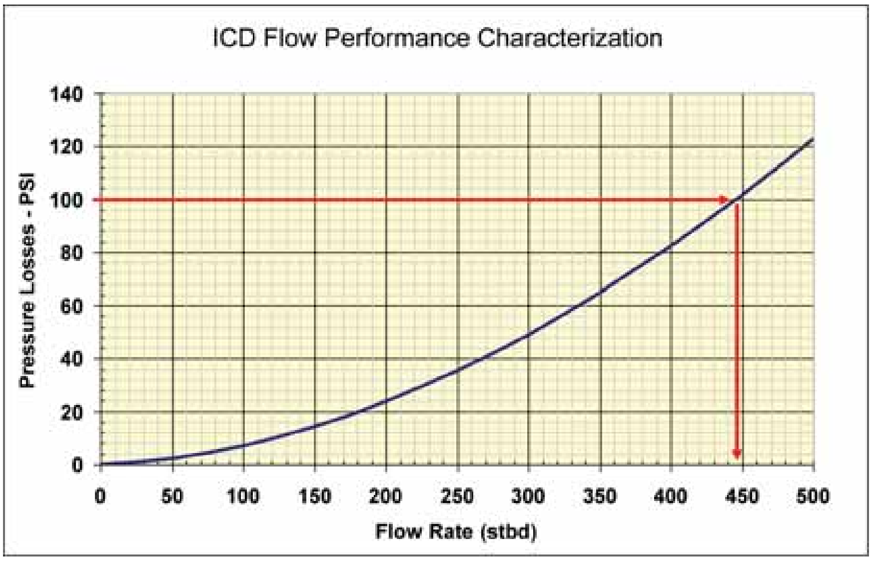


Figure 11. ICD Flow Performance Characterization.

well to optimize the number of ICD joints to run in. In fact the pressure drop through the completion (so the equalization effect) is directly dependent on the rate per joint of PICD. In cases where the total liquid rate, during the well life, is considerably less than the designed one, the applied pressure drop will be too small, the completion will become almost transparent to flow and the equalization effect will consequently decrease, losing the fluid influx control.

• Total bottomhole pressure drawdown at downhole conditions.This is based on the expected PI, which is the single most important factor to be determined for the application of PICD in a specific well. This information is very important to define the final PICD number of joint. Once a PICD system is installed, an additional pressure drop has to be considered while producing the well. The total downhole pressure drawdown (SBHP-FBHP) is due to two different contributions: pressure drop across the PICD completion (ΔPICD) and pressure drawdown at the reservoir (ΔPSandface). To guarantee good fluid flow equalization, the average pressure drop across the ICD completion has to be equal or higher than the pressure drop at the sandface (Figure 10).

This rule of thumb comes from several hundreds of wells installed in the last decade and can also be confirmed theoretically from simulations. This became the most important best practice when designing PICD completion and the most critical criterion for a PICD candidate selection. The higher the PI the more beneficial will be the PICD completion. If the PI is low, other parameters should be considered in order to assess the applicability of a PICD completion:

- Heterogeneities present along the wellbore
- Mobility control (oil/water or oil/gas)
- Available drawdown
- Artificial lift

Optimum number of PICD to install in the well. All the PICDs available on the market can be characterized by the Flow Performance Curve (Figure 11). This curve is fundamental to evaluating the total number of PICDs based on average PICD pressure drop. Entering the pressure drop inside the PICD (Y axis) the output datum is the oil rate per PICD (X axis). Dividing the total liquid target rate at downhole condition by this output, the total number of PICDs is defined.

If the number of PICDs is fixed for any reasons, for example due to the fact that in some unconsolidated formations it is good practice to cover the entire sand pay with screens, the graph can be used backwards, starting from the rate per PICD and selecting the right FRR that gives the desired pressure drop through the completion.

Passive Inflow Control Device Modeling

As has been discussed in the previous section, the horizontal and multilateral well completions can be optimized, distributing the pressure drop through the completion. The main idea behind this optimization process is to add more flow resistance in those areas with less flow resistance in the porous media, and vice versa. Such aspects as: reservoir heterogeneities, heel to toe effects, mobility ratio and differential reservoir pressure are affecting the selection of the optimum inflow control device geometry along the horizontal lateral.

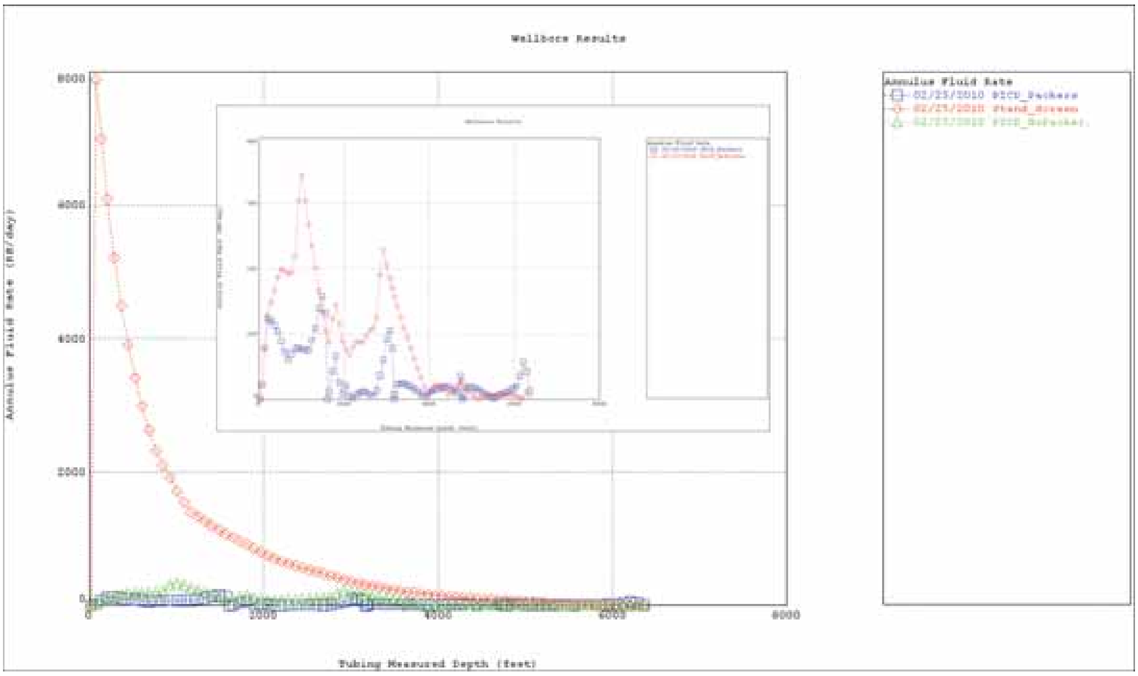


Figure 12. Annulus flow behavior (Hole size – OD PICD) for standard screen and PICD.

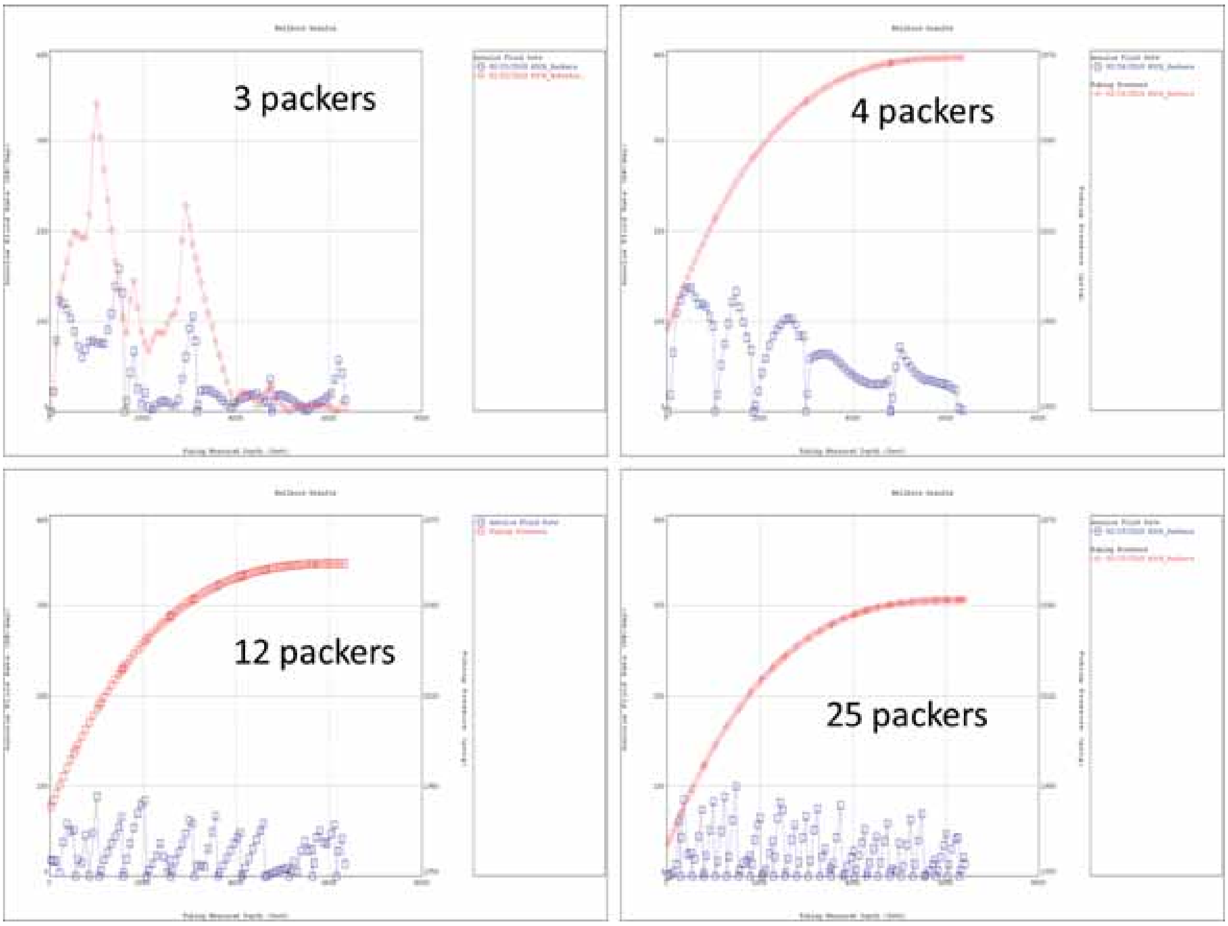


Figure 13. Annulus flow and tubing pressure as function of packer numbers.

Two approaches have been used, over the last few years, to determine the effects of the parameters involved in the pressure drop estimation from the reservoir pressure to flowing bottom hole pressure (or tubing head pressure): the steady state and transient approaches. The main difference between both approaches is the fluid saturation in the sand face; the transient approach determines the fluid saturation in each time step and therefore the water, oil and gas evolution. The steady state approach is useful to determine the pressure drop required in the completion to equalize the flow and the transient approach can estimate the fluid forecast.

Numerical simulations, as well as field cases, have shown the value added for PICDs[5] in horizontal and multilateral wells. However, the applicability of this technology is a function of reservoir and fluid type, PICD geometry type, flow rate target (and therefore available drawdown) as well as completion type, as was described in the previous section. In cases where the well productivity is not good enough this technology could not be used. However, if the target is to handle heterogeneities or mobility ratio (for instance gas wells with water production) then PICD in horizontal (or vertical with high reservoir thickness) or deviated wells could be an interesting technology to be considered.

Two well completion options can be considered: gravel pack or open annulus. Both cases have radial and lineal flow. In the open annulus case the fluid flow traveling in the annulus space, between open hole and OD screen, is higher than the gravel pack case. Therefore, from the modeling point of view, the open annulus case must have to consider mechanical (packers) options to minimize this flow condition.

The PICD application design consists in determining: the geometry type, the size, the joint numbers, the optimum flow resistance rating distribution and the packers (amount and distribution) required (if open annulus is the case). This paper focuses on analyzing the open annulus case. The gravel pack case requires additional consideration in the PICD design to guarantee that the gravel can be pumped through the PICD and therefore have a good gravel pack[10].

It has been found through experience that in order to reduce the simulation numbers, to determine the optimum PICD design, it is highly recommended to follow this procedure:

- Set up Fluid and Reservoir Properties, Well Completion and Operational Conditions (production target). There are other important variables to analyze in the ICD design, such as: well trajectory, geology, well interference, pressure maintenance, optimum flow rate or flowing bottom hole pressure along the asset life cyle that are not going to be analyzed in this paper. So far, it is our intent to describe the importance of selecting the optimum PICD setting (uniform or variable setting design).
- Establish a PICD well completion base case (no packers) and uniform PICD settings (same geometry or flow resistance rating). One recommendable starting point is selected geometry with 1.6 FRR as base line.
- Run simulation and analyze the annulus flow behavior. If the amount of fluid flow in the annulus is relatively high then evaluate the optimum packer's number and position along the horizontal. The packer's number and position is a function of reservoir permeability profile (most important variable, there are other variables to be considered). The higher the number of packers or compartments the better the flow profile in the base pipe is. It is an iterative process.
- Once the packers are located in the right place it would be recommended to analyze if the flow resistance rating (geometry) setting selected is enough to equalize the influx. If it is not the case then it would be recommended to evaluate by trial and error the optimum flow resistance setting distribution (this ICD design is called variable setting design). First trial could be add higher flow resistance rating in those reservoir areas with less flow resistance (high permeability) in the porous media and vice versa. The final ICD design is a trade off between optimum ICD flow resistance located in place and the total drawdown. In some cases the optimum ICD flow resistance produces high pressure drop in the completion. However, the ICD flow resistance settings can be changed (or reduced) in order to satisfy the drawdown requirements (for instance, if there are artificial lift constraints).
- Compare typical standard screen versus PICD flow behavior. The main difference between standard screen and PICD is the pressure drop across the equipment. The pressure drop through the standard screen is negligible (approximately zero). There are several technical points to be considered in the decision making process, to use PICD in the well completion: minimize the annulus flow, increase radial flow into production tubing, minimize flow velocity per feet produced, delay water breakthough and maximize oil recovery are the most relevant technical points.

The following example shows the implementation of the steps described previously. A numerical simulator (reveal from Petroleum Expert) was used to quantify the impact

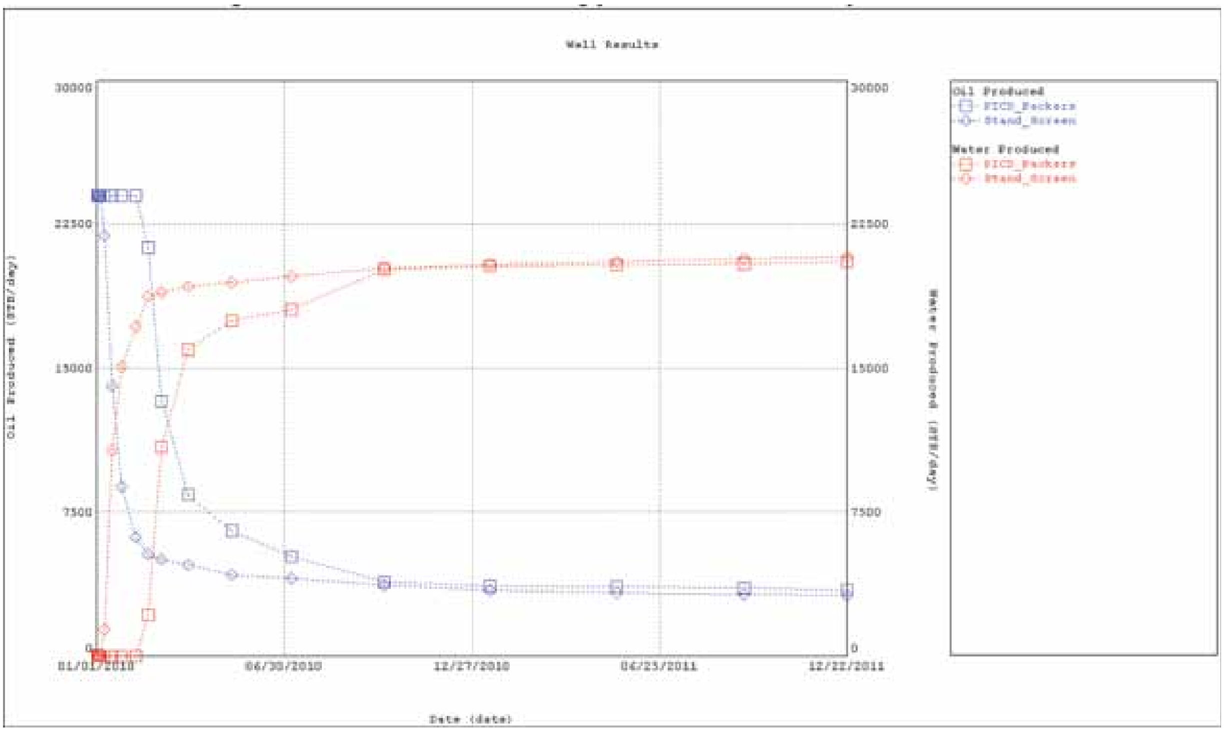


Figure 14. Oil and water production forecast for standard screen and PICD completion.

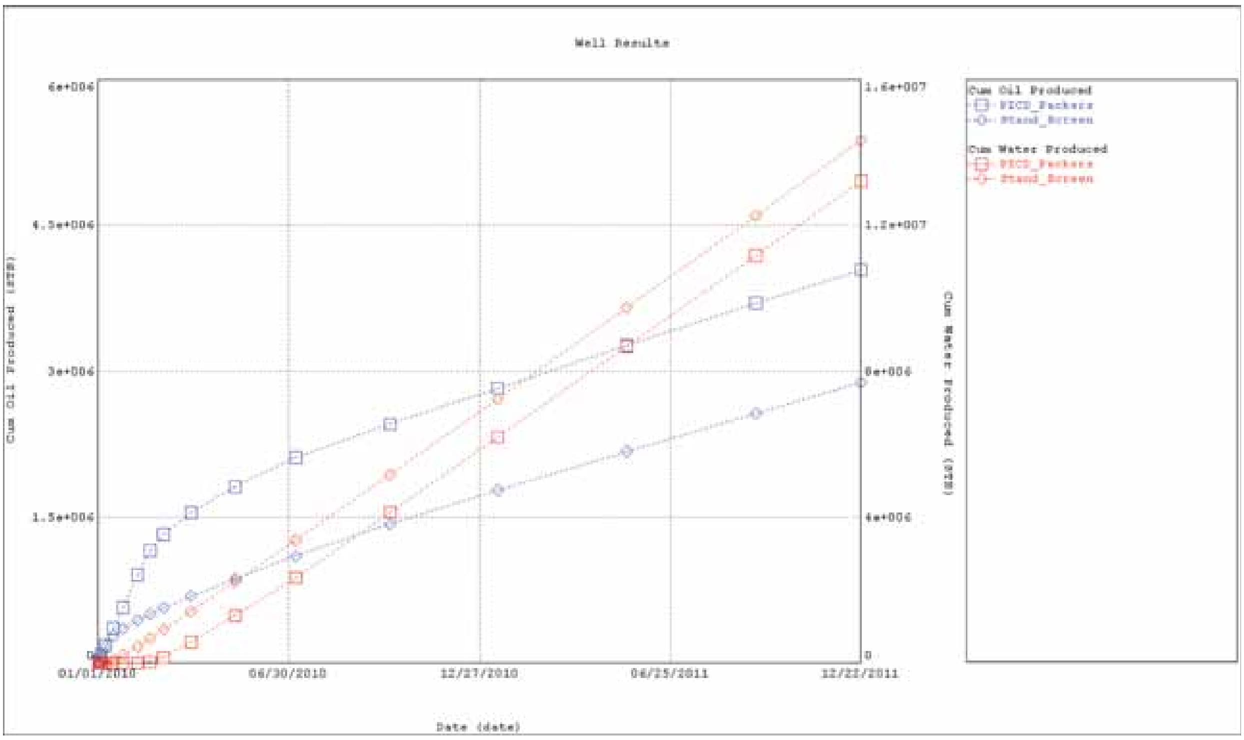


Figure 15. Oil and water cumulative production for standar screen and PICD completion.

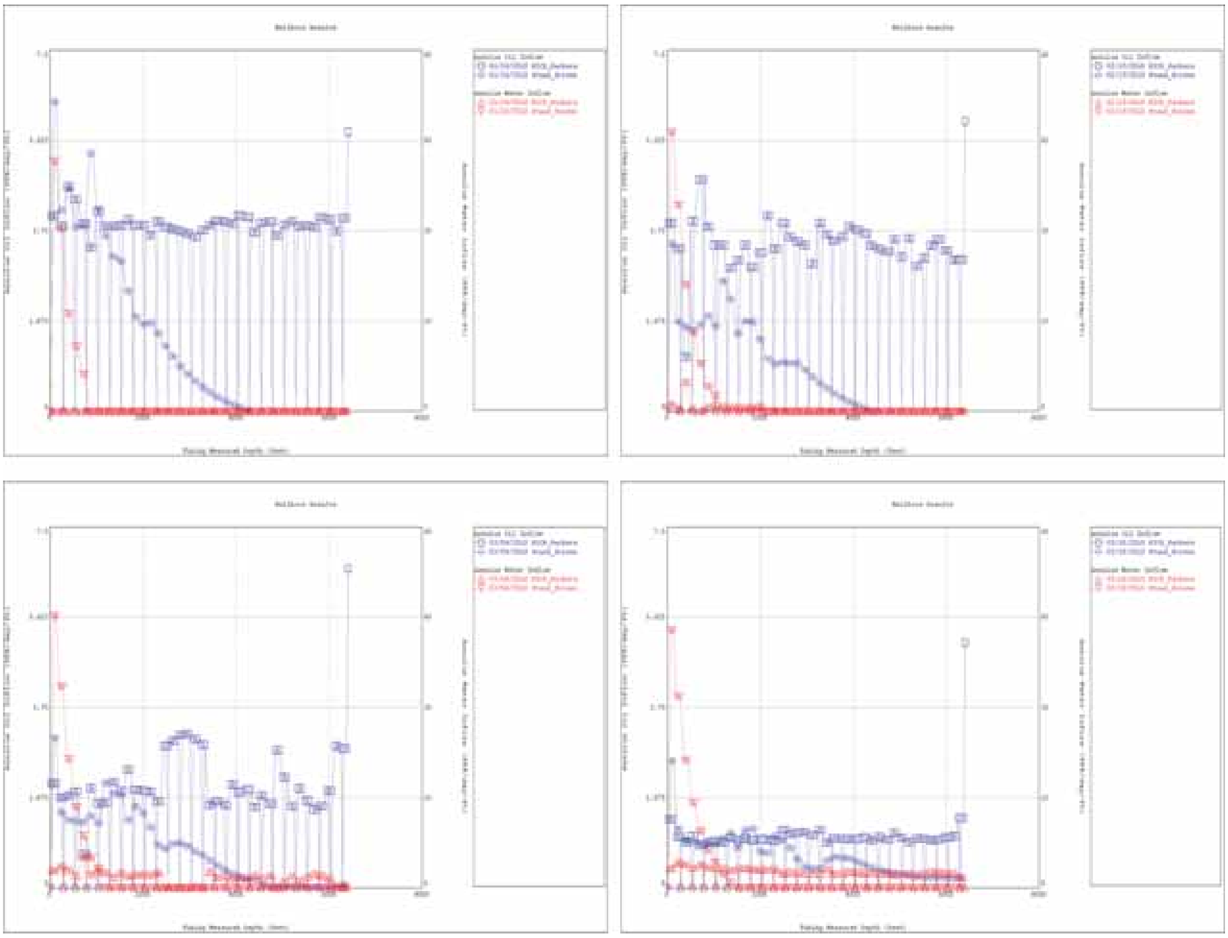


Figure 16. Oil and water influx as function of time, for standard screen and PICD completion.

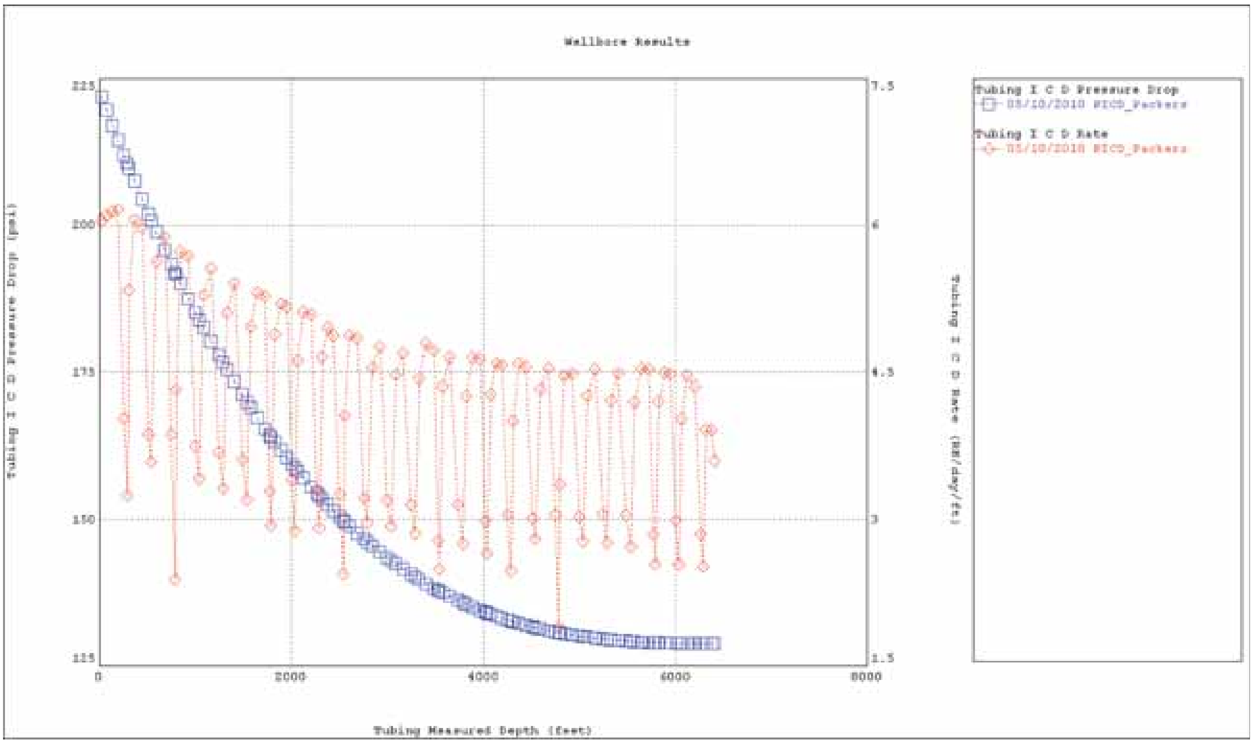


Figure 17. Flow rate and pressure drop through PICD.

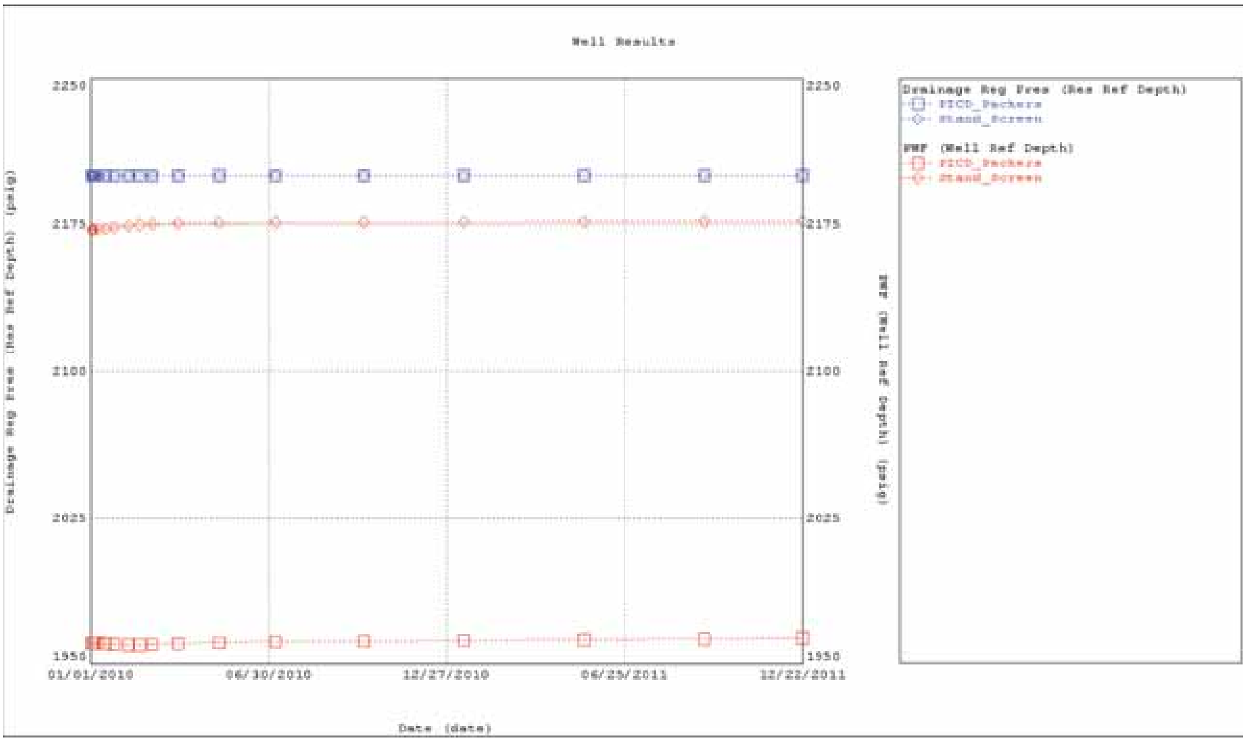


Figure 18. Flowing bottom hole pressure and reservoir pressure for standard screen and PICD.

of the variables affecting the influx along the horizontal section. It was considered three control volumes with identical reservoir (porosity – 29% and permeability – 8 Darcy) and fluid properties. The main difference is the well completion type; one control volume considers a PICD completion without packers (pressure drop across the completion), the other considers the PICD with packers and the final one a standard screen completion (no pressure drop across completion). The block size was 160 x 200 x 10 ft. The hole size was 8½-in., 5-in. base pipe & 6.54-in OD screen. Horizontal well length is 6400 ft. The pressure drop flow performance characteristic used to describe the passive inflow control device design is the same as presented by Coronado et al[6]. This particular modeling set-up give us the three well completion behaviors in one run (simulation), which allows us to analyze all of them in the same plot at the same time.

This example considers a homogeneous reservoir; in a heterogeneous environment the compartmentalization play an important role in order to improve the influx. Figure 12 to 15 show the plots that are normally used to analyze the ICD effects on the reservoir behavior; Figure 12 show the annulus flow between hole size and OD screen or PICD, Figure 13 represents the annulus flow and tubing pressure, Figure 14 shows the production forecast and the Figure 15 shows the cumulative oil and water production. Each plot has three lines which correspond to standard screen, with and without PICD.

Figure 12 analyzes the amount of fluid traveling in the annulus space. In order to improve the influx it is necessary to incorporate this amount of fluid into the base pipe. The standard screen completion (red line) shows a significant amount of fluid in the annulus, the PICD completions (blue and green) show less fluid in the annulus space. The PICD without packers showz the point where it will be recommendable to locate a packer (maximum annulus flow rate). The PICD with packers shows the annulus flow behavior considering three packers (one packer each 1560 ft).

Figure 13 shows the annulus and tubing pressure once the optimum packer number is determined. The optimum packer number was determined reducing the annulus flow. The flowing bottom hole pressure is reduced while the packer number is increased; this means that more pressure is required to transform the lineal flow per radial flow. The additional pressure drop through the completion allows the influx to equalize and therefore improves the oil production from those areas with more flow resistance in the porous media. The higher compartmentalization (packer number) the better the radial flow behavior and influx equalization.

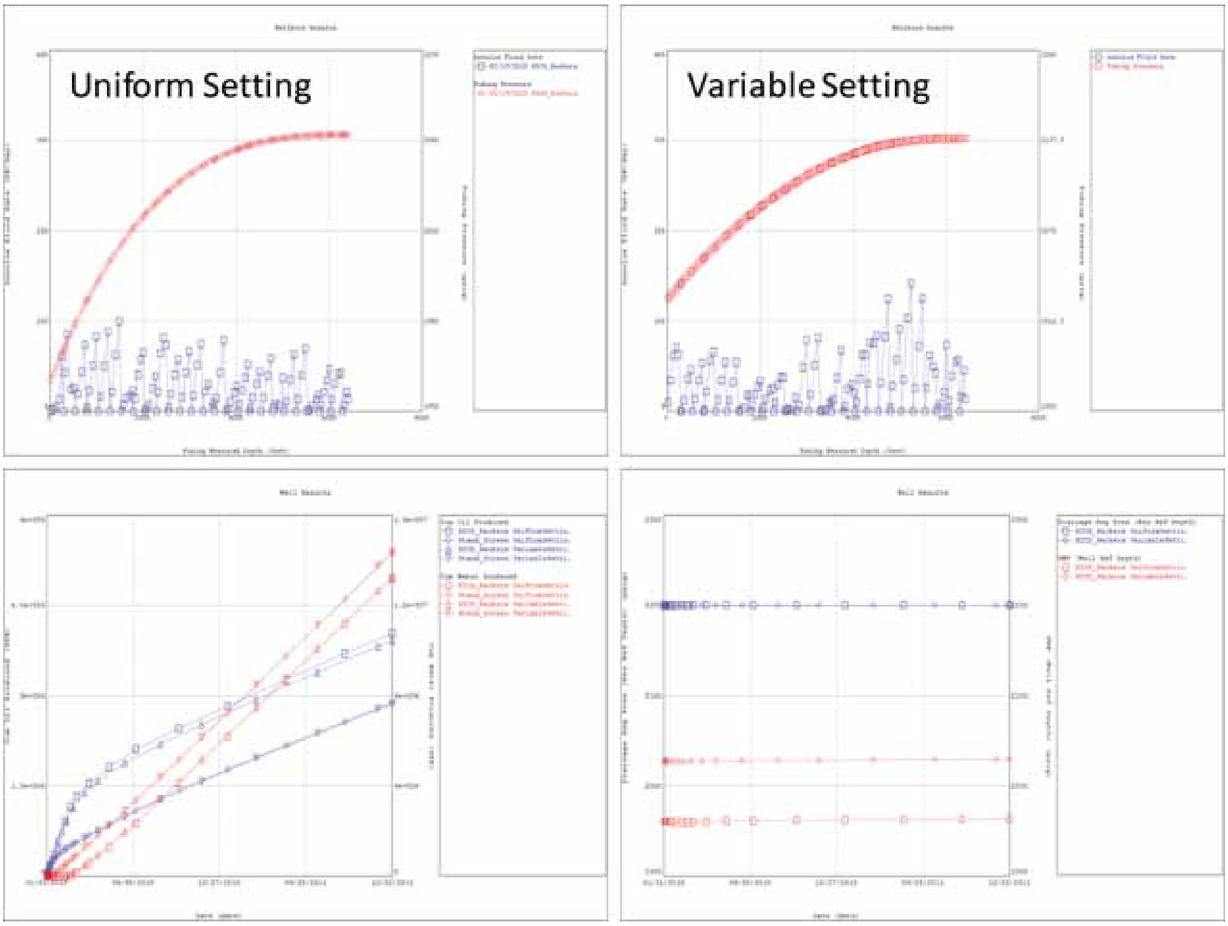


Figure 19. Uniform and variable setting design effect.

Figure 14 shows the oil and water production for PICD and standard screen completion. Two technical points can be observed in this figure: the delay in the water breakthough and therefore more oil production per unit time.

Figure 16 shows the oil and water influx at four unit times. The four plots in this figure show the equalization effects as well as water control along the horizontal section. It is also important to analyze the pressure drop across the PICD; the pressure drop is a function of total downhole flow rate per PICD joint, PICD geometry and fluid properties. Figure 17 shows the ICD pressure drop and ICD flow rate/ft. In sandstone reservoir joints of 40 ft have been used for oil producers. In some cases the PICD joint can be reduced in order to increase the flow area and decrease the pressure drop, for instance water injectors.

Figure 18 shows the flowing bottom hole pressure and reservoir pressure. The standard screen completion requires 24 psi to achieve the production target (24000 stbd) and PICD completion require 238 psi. The PICD drawdown can be reduced analyzing the flow resistance rating effects. So far, the results have shown that 1.6 FRR is good enough to equalize the influx and maximize the oil production.

However, what could be the effect of using variable instead of uniform PICD setting design? The effect is observed in the equalization of the influx as well as in the drawdown. Figure 19 shows the total drawdown for uniform and variable setting PICD design. The variable setting design requires less drawdown (~170psi) than uniform setting (~238psi); in the variable design case the equalization effects can be achieved as well as delay in the water breakthough. However, the production cost (or penalty) of using variable rather than uniform setting is ~100000 stbd in two years (~138 bpd during two years) with the same water production. Fundamentally, the use of 68 psi less in the drawdown for two years would affect 100000 stbd. If for operational reasons it is not possible to pay for this additional drawdown then variable setting design will be the solution; otherwise uniform setting design is a better solution.

Figure 20 shows the 3D view for the cases analyzed in this example. The control volume in the middle consid-

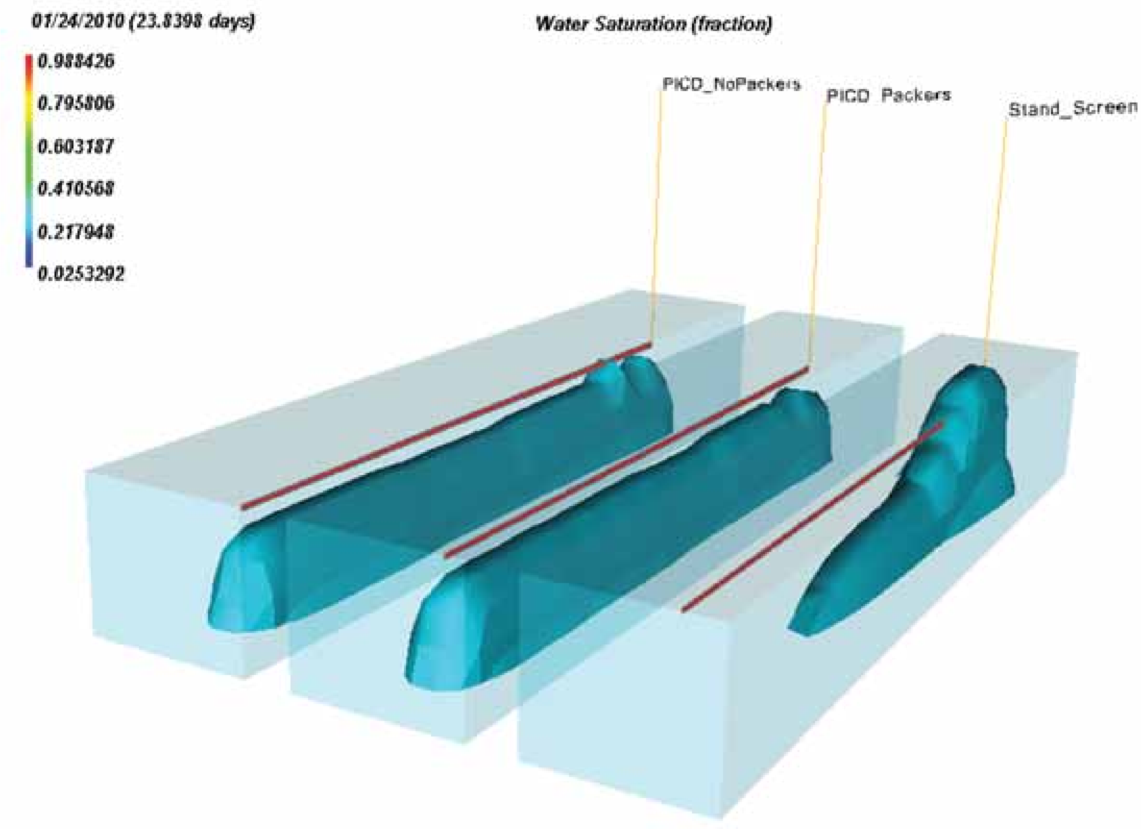


Figure 20. Standard screen and PICD flow behavior with and without packers.

ers packers; the flow behavior in the heel is improved considerably at the heel when compared with the PICD case with no packers.

The PICD design is case by case as described before; achieving the optimum design is a trade off between the drawdown and the equipment available in situ. It is also important to consider the PICD stock to maintain in the company. In some cases it would be better to keep the same flow resistance rating rather than different FRR. If we refer to rig adjustability, then is important to consider the PICD flow performance; not all the PICDs deliver the same performance. Garcia G.[4] et al showed the PICD effect on reservoir behavior; the hybrid PICD design delivers an extraordinary flow performance and is adjustable at the rig.

Evaluation of PICD Systems

After a PICD system has been installed in a well, a post job analysis should be performed to evaluate the results of the application. This evaluation provides useful information to identify opportunities to optimize and repair the current system, but also to improve the design and deployment of future applications. The post job analysis should be done just after the deployment and carried on during the production cycle of the well.

Deployment.
An as per plan deployment of the system at the target depth, almost certainly distinguishes a successful application from a non successful one. The PICD system is designed to have compartments, certain numbers of PICDs between open hole packers, covering the wellbore length to equalize the influx or flow rate per foot coming from the reservoir. In addition, the open hole packers placed in the PICD system are to be set at a particular depth, where the open hole size provides a place for an effective packer seal. If any open hole packer is not effectively sealing, the compartmentalization effect would be dismissed. Therefore, a deviation of the deployment target depth will definitely modify the expected performance of the PICD system. A worse case scenario is present if blanked sections, no PICDs between packers, are run in the PICD system.

Blanked sections are usually run to isolate very high permeability sections, i.e. open fractures, or sections with a high saturation of undesirable fluids, such as water. A deviation of the deployment target depth definitely exposes these sections to PICDs, decreasing the equalization goal and accelerating the breakthrough of non desirable fluids.

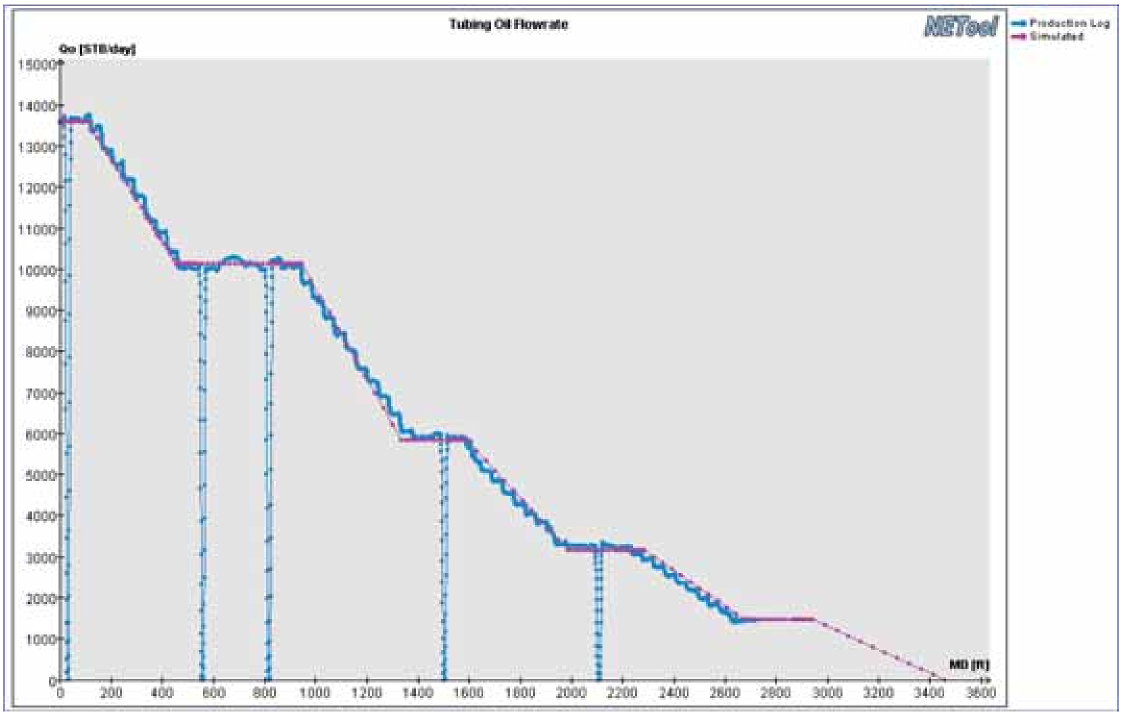


Figure 21. Production Log and Simulated Tubing Oil Flowrate.

Production monitoring

The passive characteristic of the PICD system limits the optimization process as no adjustment to the PICDs can be performed, but fluid production monitoring over time provides useful information about the performance of the well. Production monitoring identifies the production of undesirable fluids, i.e. water or gas in an oil well, and will trigger either surface choke changes to modify the proportion of the producing fluids or reparation opportunities.

Adjustment at the surface choke decreases or increases the bottom hole flowing pressure, and consequently decreases or increases the total pressure drawdown and therefore the influx from the reservoir. In the event of downhole multiphase production, the characteristics of the PICDs and the fluid properties of each phase determine the changes in pressure drop across the PICDs, and the resulting changes in the influx from the reservoir at each compartment. These influx changes per compartment will modify the proportion of the producing fluid.

A new 'generation' of PICDs is changing the passive characteristic of the PICD system incorporating a Sliding Sleeve to each PICD, and providing the capability to selectively open or close each one[11]. This characteristic will completely modify the optimization process for a PICD system as undesirable fluids can be either minimized or completely isolated, and the equalization effect can be maximized. Most likely, for these Sliding Sleeve PICD systems, downhole information is required to positively identify the PICDs that need to be actuated.

Production Logging

Production logging provides a full evaluation of the static conditions at the near wellbore reservoir and the dynamic conditions inside the tubing/liner of a PICD system. The dynamic conditions data conclusively identify the fluid entry points, phases and amount being produced, while the static condition data provide the near wellbore reservoir pressure.

A production log is basically run either to diagnose the performance of the system in terms of equalization effect or to identify the undesirable fluid entry points for remediation work. Therefore, the production log can be run either in the early life of the well or after a long time in production. It is common practice to perform a production log in the early life of the wells in those fields with a short running history of PICD systems. In this case the main objective is to verify the equalization ef-

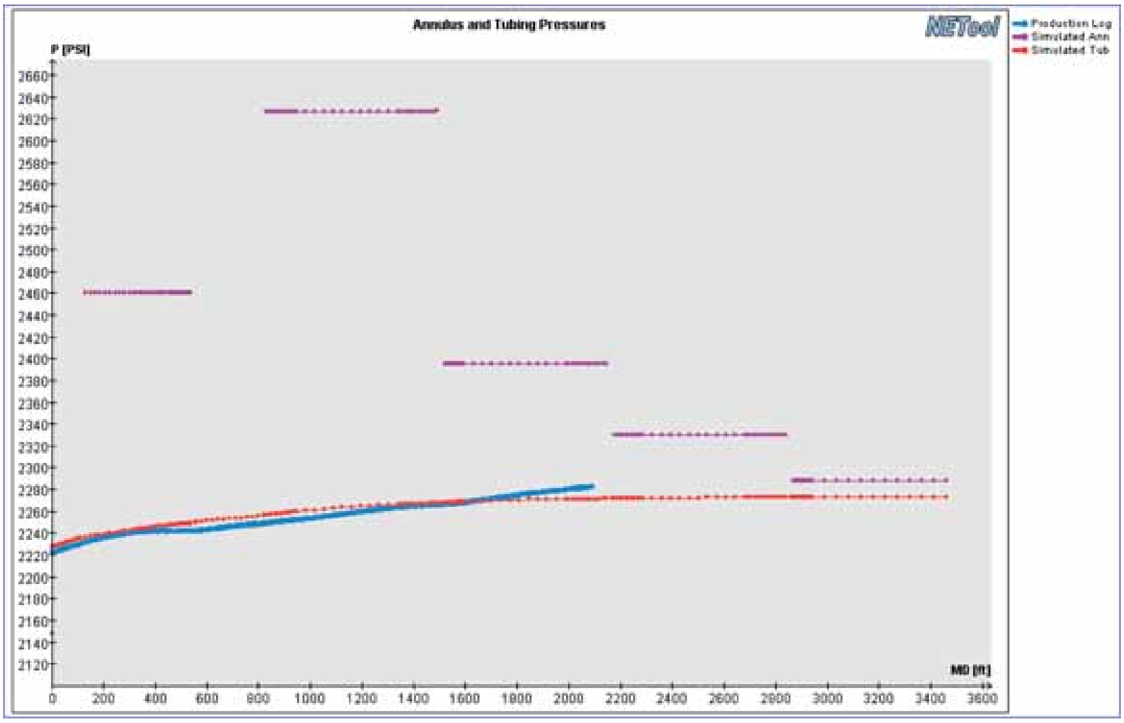


Figure 22. Production Log and Simulated Tubing and Annulus Pressures.

fect of the PICD system and to compare its performance with a simulated barefoot completion scenario.

The production log identifies and quantifies the flow rate of each fluid phase coming from each PICD and not the influx coming from the reservoir. So a steady state near wellbore simulator is needed to infer the influx coming from the reservoir. This influx determines the level of equalization for a particular PICD system. Due to the large heterogeneity of reservoir properties in different layers, complexity of the geological features and the fluid dynamic within the wellbore, it is very challenging to reproduce the actual production profile in the simulator. The most common approach to simulate a PICD system is modifying the reservoir permeability distribution and/or the well skin.

A production log reproduced in a steady state near wellbore simulation provides very useful information to evaluate PICD system performance. A production log from a dry oil well in the Middle East was input to a steady state near wellbore simulator, and calibrated accordingly to match the production profile along the wellbore. Figure 21 shows the tubing oil flow rate from a production log and the matched tubing oil flow rate generated by the simulator, and Figure 22 shows the bottom hole flowing pressure from a production log and the simulated pressure values. In both cases a good match was obtained by adjustment of the permeability profile. The simulated reservoir influxes for the PICD system and for the barefoot case are shown in Figure 23. These two plots show the equalization effects generated by the PICD system, and the difference in performance compared with a barefoot completion.

The production log also provides the information required to optimize a Sliding Sleeve PICD system. The log will identify and quantify the flow rate of each fluid phase coming from each Sliding Sleeve PICD, and with the same coiled tubing operation, using an additional trip, the sliding sleeve shifting tool is run to selectively close or open the required PICD to either maximize the equalization effect or to control the production of undesirable fluids.

Distributive Temperature Sensor

Permanent downhole monitoring can provide valuable information for production decisions without the need to perform an intervention to collect data. One of the commercial permanent monitoring technologies is the fiber-optic DTS, which can record the wellbore temperature profile in real time with significant accuracy and resolution. A key potential application for DTS data is to profile production of wells completed with PICDs[12].

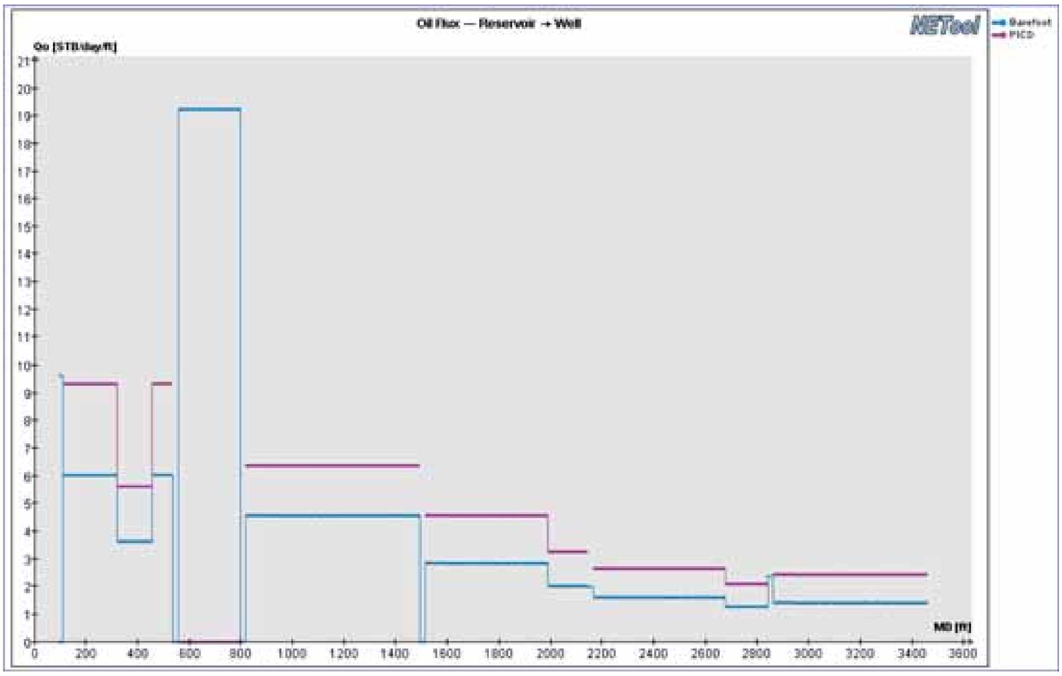


Figure 23. Reservoir to Well Oil Flux: PICD system and barefoot.

Thermal models have recently been developed for single-phase and multiphase fluid flow along a vertical, deviated or horizontal well. The models can be applied for both wellbore temperature prediction (forward modeling) and for flow profiling using a measured temperature profile (inverse problem). The models have successfully been applied to investigating key thermal characteristics of single-phase and multiphase fluid flow along a wellbore. In particular, the dependence of wellbore temperature upon phases, flow profile, fluid type, fluid properties, well deviation, and Joule-Thomson effects[12].

Remediation of PICD Systems

Most of the PICD applications are non retrievable systems. Liner Hangers and Packers, and Open Hole Packers run in combination with PICDs add technical difficulties and high costs to any retrieving operation. For unconsolidated formations, the potential wellbore collapse eliminates the possibilitiy of retrieving these systems.

Remediation alternatives for PICD systems are achievable by Thru-Tubing isolation operations. The alternatives are basically to isolate the lowermost compartments, by a plug & abandon kit, intermediate, by inflatable or expandable straddles or uppermost compartments, by a tie-back seal assembly. Re-completion with Thru-Tubing operations is a viable, cost-effective approach to remedy undesirable fluid influx from completion misplacement or gas and/or water breakthroughs.

Even though there are no published cases in the literature, an operating company in the Middle East has reported successful isolation of watered-out compartments in horizontal wells completed with PICDs. Tie Back Seal Assemblies were used to isolate undesirable fluid influx in the upper compartments of PICD completions. It was reported that in two cases the wells were recovered, with excellent post-workover oil production. This technology could also be applied to intermediate compartments, although bottom compartments might be best isolated by Thru-Tubing Inflatables.

Figure 24 shows an example schematic with a Tie Back Seal Assembly completion for the isolation of two upper compartments in a PICD completion.

For Sliding Sleeve PICD systems[1], a remediation job can be performed by Coiled Tubing operations. A Sliding Sleeve shifting tool needs to be run in the bottom of the coiled tubing, and selectively close PICDs to restrict or isolate a compartment, or selectively open to adjust the performance of the system.

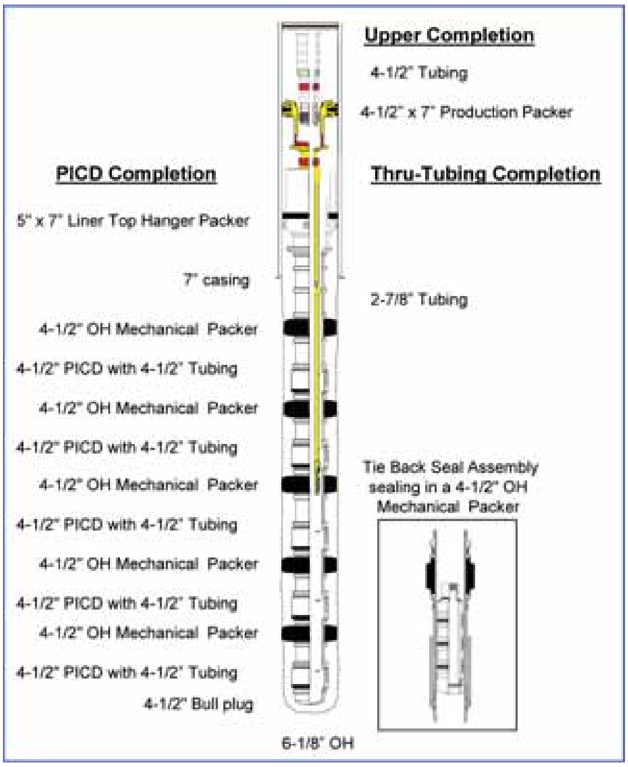


Figure 24. Isolation Schematic with a Tie Back Seal Assembly Completion.

Conclusions

- The optimum PICD selection is largely a function of production fluid, for an oil production PICD application it is highly recommendable to use a hydrid design and gas application can be used helix design[4].
- The PICD flow performance characteristic will drive the optimum design. It means that uniform or variable setting design is affected by the PICD type. In the long term it is highly recommended to use low velocity design and uniform settings. Variable settings design could be used to reduce the pressure drop across the completion.
- Increasing the compartment number (or packer number) can improve the influx as well as transforming the lineal flow (annulus flow, hole size to OD PICD) into radial flow.
- The higher the pressure drop across the completion (optimum distributed along the horizontal section) the better the water control.
- The production logging tool is a key factor in diagnosing PICD flow behavior. The use of downhole fluid temperature will transform the PICD current diagnostic technique since the interpretation of the Joule Thompson coefficient can show fluid changes per PICD joint.
- The use of sliding sleeve with PICD is an optimum solution, from a passive point of view, to water shut off.

Acknowledgements

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SI Metric Conversion Factors

psi	×	6.894757	E+00	= kPa
lbf	×	4.448222	E+00	= N
in	×	2.54*	E+00	= cm

*conversion factor is exact.

References

1. Peterson E., Coronado M., Garcia L., Garcia G.: 'Well Completion Applications for the Latest-Generation Low Viscosity Sensitive Passive Inflow Control Device'. Paper SPE128481 presented at the Drilling Conference and Exhibition, New Orleans, Louisiana, February 2010

2. Garcia L., Coronado M., Russell R., Garcia G., Peterson E.: 'The First Passive Inflow Control Device That Maximizes Productivity During Every Phases of a Well's Life' paper IPTC 13863 presented at the 2009 International Petroleum Technology Conference, Doha, Qatar, December 7-9.

3. Cochran, Travis. Test Report No. 1A1-175-05C. 'Adjustable Hybrid Inflow Control Device (PICD) Plugging Resistance Testing,' September 2009.

4. Garcia G., Garcia L, Russell R.: 'The Next Generation PICD, a Fit for Purpose Design to Meet Reservoir Requirements'. Passive Inflow Control Technology Forum (PICT). Copenhagen, Denmark, October 27-28, 2009.

5. Garcia, G, Coronado, M. and Gavioli P.: 'Identifying Well Completion Applications for Passive Inflow Control Devices,' paper SPE 124349 presented at the 2009 SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, October 4-7.

6. Coronado, M., Garcia, L., Russell, R., Garcia, G. and Peterson, E.: 'New Inflow Control Device Reduces Fluid Viscosity Sensitivity and Maintains Erosion Resistance' paper OTC 19811 presented at the 2009 Offshore Technology Conference, Houston, TX., May 4-7.

7. Garcia Gonzalo. 'ICD Flow Characterization'. October 2008. Houston TX. Technical Service Sand Control Report.

8. Gavioli Paolo, Garcia Gonzalo, Garcia Luis. 'Evaluating Four Types of Passive Inflow Control Devices ICD Performance Curves'. Passive Inflow Control Technology Forum. 24th October 2008. Perth, Australia

9. Augustine, J.: 'Advanced Completion Technology Creates a New Reality for Common Oil Field Myths'. SPE100316. 2006

10. Augustine J., Mathis S., Nguyen H., Cann C., Gill J.: 'World's First Gravel-Packed Uniform Inflow Control Completion'. SPE103195. 2006

11. Augustine, J.: 'An Investigation of the Economic Benefit of Inflow Control on Horizontal Using a Reservoir – Wellbore Couple Model' paper SPE 78293 presented at the 13th European Petroleum Conference, Aberdeen, Scotland, October 29-31, 2002.

12. Liang-Biao Ouyang and Dave Belanger: 'Flow Profiling by Distributed Temperature Sensor (DTS) System – Expectation and Reality', SPE 90541, SPE, Chevron Corp. May 2006

13. Drew Hembling and Adeyinka Soremi, SPE, Saudi Aramco; Neale Carter, SPE, TEndeka; Garth NAldrett, SPE, FloQuest: 'A Case History: First Real-Time Digital Flow Profiling of a Passive Inflow Control Device (ICD) Completion' SPE 122448 paper presented at the 2009 SPE Asia Pacific Oil & Gas Conference and Exhibition, Jakarta, Indonesia.

Nomenclature

FRR Flow Resistance Rating
PICD Passive Inflow Control Device
OH Open hole
cP Fluid Viscosity - Centipoise

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

Welcome Message by the Chairman

I would like to welcome you to the 2011 Annual Technical Symposium and Exhibition (2011 ATS&E). Our event is organized by the Saudi Arabian Section of the Society of Petroleum Engineers (SPE SAS) and the Dhahran Geosciences Society (DGS). The collaboration between the two societies represents a fruitful integration between engineering and geosciences.

This technical summit is the largest annual gathering for engineers and geoscientists in the region. Over the past years, the Symposium has been growing considerably 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 received abstracts, the 2011 ATS&E broke every record throughout its history. With this powerful momentum, we look forward to another outstanding Symposium in the year 2011.

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. New technologies development is the essential mean to meet the ever increasing energy demands, especially with the fact that new oil and gas discoveries/production are more challenging.

The 2011 ATS&E will have four pre-event courses and a workshop, 20 technical sessions, a panel discussion and a poster session. In addition, there will be an exhibition showcasing new technology advancements. As part of the SPE SAS Young Professionals activities in the 2011 ATS&E, the program will include an open day for high school students in Arabic entitled "Your Future Career" to introduce them to various engineering and sciences disciplines. This aims at helping the students in their selection of future college majors.

Saudi Arabia Oil and Gas will be the Official Publication and will provide coverage of the ATS&E.

Thank you for supporting our event and I have no doubt that it will be a gratifying experience for you.

Dr. Ghaithan A. Al-Muntasheri
Chairman, 2011 SPE SAS/DGS Annual Technical
Symposium & Exhibition

SPE-SAS 2011 Technical Sessions

Session 1 **Monday, May 16** **Hall-A**

Reservoir Geology & Geophysics (1) **08:00 - 09:15**

Session Chairpersons: Mohammad Al Masrahy, Saudi Aramco
Brian Wallick, Saudi Aramco

8:00-8:25	SPE-SAS 889	Internal Multiples Elimination of Land Data using the Inverse Scattering Series *Ghada Sindi, Qiang Fu, Yi Luo, Panos G. Kelamis, ShouDong Huo and Shih-Ying Hsu; Saudi Aramco*
8:25-8:50	SPE-SAS 1002	Fracture Imaging using Azimuthal Prestack Depth Migration *Krzysztof Sliz, Saudi Aramco*
8:50-9:15	SPE-SAS 1206	Understanding Heavy Oil Fluid Sensitivity for Seismic Reservoir Characterization Workflows *Aiman Bakhorji and Mohammed Al-Otaibi, Saudi Aramco and Mukaram Ahmed; Schlumberger*

Session 2 **Monday, May 16** **Hall-B**

New Emerging Technologies in the Upstream Oil & Gas **08:00 - 09:15**

Session Chairpersons: Khaled Al Kilany, Saudi Aramco
Konstantinos Zormpalas, Saudi Aramco

8:00-8:25	SPE-SAS 711	NanoEmulsion for Non-Aqueous Mud Removal in Wellbore *Wasan Saphanuchart , Yoong Shang Loke, Sritharan Nadarajan, Chun Hwa Se, and Chia Ni Lim; BCI Chemical Corp.*
8:25-8:50	SPE-SAS 942	The Technologist Development Program: Saudi Aramco's Strategy to Prepare Today's Professionals for Tomorrow's Challenges *Hussein Al Ali, and David G. Kersey, Saudi Aramco*
8:50-9:15	SPE-SAS 1107	Workflow Automation of a 5-Stage Gate Upstream Technology Pilot Process *Saleh M. Alsayari, Jon E. Lauritzen and Abdulrahman M. Qurtas, Saudi Aramco*

9:15-9:30	Coffee Break

Session 3 — Monday, May 16 — Hall-A

Drilling Operations (1) 09.30 - 11:15

Session Chairpersons: Qusai Darugar, Baker Hughes
Hassan Al Sarrani, Saudi Aramco

9:30-10:00	Invited Speaker: Mr. Dave Clark Director, Dhahran Research and Technology Center Baker Hughes, Saudi Arabia	
10:00-10:25	SPE-SAS 1106	The Application of Real Time Downhole Drilling Dynamic Signatures as a Possible Early Indicator of Lithology Changes *Cliff Kirby, Baker Hughes, Mark Brinsdon, Baker Hughes and Nawaf Al-Shaker, Saudi Aramco*
10:25-10:50	SPE-SAS 878	Drilling Solutions to Improve Performance in Deep Gas Drilling in Saudi Arabia *Khalid Nawaz, Shaji Thomas, Saudi Aramco; Jaywant Verma, and Sukesh Ganda, Schlumberger*
10:50-11:15	SPE-SAS 844	A Total Systems Approach Delivers Back-to-Back Record Footage Records in Saudi Arabia *Khalid Nawaz, Arris Riskiawan, Shaji Thomas, Saudi Aramco;, Van Brackin, Ryan Seike and Nicholas Lyons, Baker Hughes*

Session 4 — Monday, May 16 — Hall-B

Unconventional Resources 09.30 - 11:15

Session Chairpersons: Khalid Al Naimi, Saudi Aramco
Abdelaziz Al Khlaifat, Weatherford

09:30-10:00	Invited Speaker: Mr. Robert H. Gales Vice President, Unconventional Resources Projects Weatherford	
10:00-10:25	SPE-SAS 1153	Horizontal Wells Drilling Activity in South Texas Unconventional Gas Resources and Microseismic Hydraulic Fracturing Monitoring Application to Reduce Risk and Increases the Success Rate *Abu Mohammed Sani, and Efe Ejofodomi, Schlumberger*
10:25-10:50	SPE-SAS 1077	Tight Gas Petrophysical Challenges in Saudi Aramco *David Forsyth, Saudi Aramco*

10:50-11:15	SPE-SAS 982	Deviation from Darcy's Flow in Fractured Tight Gas Sand Reservoirs *Abdelaziz Khlaifat, Hani Gutob, Weatherford and Hamid Arastoopour, Illinois Institute of Technology*

11:15-12:30	Keynote Luncheon Speaker: Mr. Martin Craighead President and Chief Operating Officer Baker Hughes	Main Hall
	Lunch & Prayer Break	
	Luncheon Generously Sponsored By Baker Hughes	

Session 5 Monday, May 16 Hall-A

Integrated Reservoir Management 12.30 - 14:15

Session Chairpersons: Salem Al Gholaiqah, Saudi Aramco
Saeed Al Mubarak, Saudi Aramco

12:30-13:00	Invited Speaker: Dr. Nabeel Al Afaleq Manager, Northern Area Reservoir Management Department Saudi Aramco	
13:00-13:25	SPE-SAS 1273	Salient Points of Petroleum Resources Management System (PRMS) – Definitions and Assessment Procedures with Application Examples *Yasin Senturk, Saudi Aramco*
13:25-13:50	SPE-SAS 1124	Selecting Optimum Completion Strategy – Examples from Saudi Arabia's Unconsolidated Unayzah Reservoir *Hassan D. Al-Anazi, Adel Al Qahtani, Zillur Rahim, Mohammad Al Masrahy, Bandar H. Al-Malki, and Adnan Al-Kanaan; Saudi Aramco*
13:50-14:15	SPE-SAS 803	Effective Reservoir Management Strategies to Revitalize Dead Producers Behind the Flood Front *Amer H. Abuhassoun and Ali S. Rabba, Saudi Aramco*

Session 6 — Monday, May 16 — Hall-B

Health, Safety and Environment — 12.30 - 14:15

Session Chairpersons: Hee Ting, Saudi Aramco
Xiaolong Cai, Saudi Aramco

12:30-13:00	Invited Speaker: Mr. Darren Franklin Country Manager, Health, Safety, Environment & Operational Excellence Halliburton	
13:00-13:25	SPE-SAS 705	Exceeding Well Life Design in Mature Fields using Well Integrity Management System *Weka Janitra Calosa, Kondur Petroleum SA*
13:25-13:50	SPE-SAS 855	An Effective Health, Safety and Environmental Management System for Production Engineering Organization *Hisham Ibrahim Al-Shuwaikhat, Saudi Aramco*
13:50-14:15	SPE-SAS 1137	Safe Execution of Sour Well Tests *Philip Bellerby, Peter Elias, Taco Hoekstra and Adrian Wevers, South Rub Al-Khali Company*

14:15-14:30	Coffee Break

Session 7 — Monday, May 16 — Hall-A

Advances in Improved Oil Recovery/Enhanced Oil Recovery (1) — 14.30 - 16:30

Session Chairpersons: Abdulrahman Al Quraishi, KACST
Ali Al Yousif, Saudi Aramco

14:30-15:00	Invited Speaker: Dr. Pacelli L. Zitha Delft University of Technology The Netherlands	
15:00-15:15		Prayer Break
15:15-15:40	SPE-SAS 754	Use of the Memory Concept to Investigate the Temperature Profile during a Thermal EOR Process *M. Enamul Hossain, Sidqi Abu-Khamsin and Abdul-Aziz Al-Helali; King Fahd University of Petroleum and Minerals*

15:40-16:05	SPE-SAS 1026	The Effect Of Suspended Solid and Oil Droplet on Particle Coalesces in Water Injection *Mohammad Ali, Abeer Alfarhan, , Ali Alhadad and Suhaib Alkhulosi; Kuwait Institute for Scientific Research*
16:05-16:30	SPE-SAS 1204	Fluid Flow Characterization of Chemical EOR Flooding: A Computerized Tomography (CT) Scan Study *Mohammed Bataweel and Hisham Nasr-El-Din; Texas A&M University*

Session 8 Monday, May 16 Hall-B

Advances in Reservoir Characterization 14.30 - 16:30

Session Chairpersons: Saleh Al Dossary, Saudi Aramco
Satya Putra, Saudi Aramco

14:30-15:00	Invited Speaker: Dr. Amos Nur Director, Rock Physics & Borehole Geophysics Stanford University, USA	
15:00-15:15		Prayer Break
15:15-15:40	SPE-SAS 969	Introducing a New Wireline Rotary Coring Tool: Experience from the Middle East *Marvin Rourke, Halliburton and Juan Torne, Halliburton*
15:40-16:05	SPE-SAS 1071	A Holistic Approach to Detect and Characterize Fractures in A Mature Middle-Eastern Oil Field *Ahmed Alhuthali, Danang Widjaja, Stig Lyngra and Francois-Michel Colomar, Saudi Aramco*
16:05-16:30	SPE-SAS 1074	Field Application of a Modified Kozeny-Carmen Correlation to Characterize Hydraulic Flow Units *Hasan Nooruddin, M. Enamul Hossain, Sharizan Sudirman and Thamer Sulaimani , Saudi Aramco*

Session 9 — Tuesday, May 17 — Hall-A

Production Operations (1) 08:00 - 09:15

Session Chairpersons: Rifat Said, Saudi Aramco
Mohamed Noui-Mehidi, Saudi Aramco

08:00-08:25	SPE-SAS 945	New Approach of Water Shut Off in Open Holes – and World First Application of using Fiber Optic with Tension-Compression Sub *Jorge E. Duarte, Rifat Said, Surajit Haldar, Mohammad Homoud, Ahmed Mahsoon, Saudi Aramco and Anton Burov, Schlumberger*
08:25-08:50	SPE-SAS 976	Mechanical Rigless Water Shut-Off (WSO) *Alaa S. Shawly, Saudi Aramco*
08:50-09:15	SPE-SAS 836	Production Enhancement of Hilly Terrain Onshore Remote Field *Shadi Hanbzazah, Mohammed Merwat and Mohammed N. Al-Khamis; Saudi Aramco*

Session 10 — Tuesday, May 17 — Hall-B

Advanced Rock Physics 08:00 - 09:15

Session Chairpersons: Aiman Bakhorji, Saudi Aramco
Abdulaziz Al Aslani, Saudi Aramco

08:00-8:25	SPE-SAS 1163	The Rock Physicochemical Basis for Time-Lapse Seismic Reservoir Monitoring of CO_2 Injection *Tiziana Vanorio; Stanford University, Amos Nur; Stanford University & Ingrain and Elizabeth Diaz, Ingrain*
08:25-8:50	SPE-SAS 1186	Effects of Carbon Dioxide Injection in Reactive Carbonates: Computational Rock Physics Basis for Time-Lapse Monitoring *Amos Nur, Ingrain & Stanford University, USA*
08:50-9:15	SPE-SAS 1049	Sensitivity of Elastic Properties to Heterogeneity in Carbonate Rocks *Ravi Sharma and Manika Prasad, Colorado School of Mines, USA*

09:15-9:30	Coffee Break

Session 11 — Tuesday, May 17 — Hall-A

Reservoir Simulation 09:30 - 11:15

Session Chairpersons: Joes Vargas-Guzman, Saudi Aramco
Shamsuddin Shenawi, Saudi Aramco

9:30-10:00	Invited Speaker: Mr. Khalid O. Al Subai Manager, Reservoir Description & Simulation Department Saudi Aramco	
10:00-10:25	SPE-SAS 1096	Triple-Porosity Models: One Further Step towards Capturing Fractured Reservoirs Heterogeneity *Hasan A Al-Ahmadi, Saudi Aramco and Robert Wattenbarger, Texas A&M University*
10:25-10:50	SPE-SAS 984	An Alternative Approach to Modeling Non-Darcy Flow for Pressure Transient Analysis in Porous and Fractured Reservoirs *Ajab M. Al-Otaibi, College of Technological Studies, Kuwait and Yu-Shu Wu, Colorado School of Mines, USA*
10:50-11:15	SPE-SAS 1260	Modeling and Simulation of Structural Deformation of Isothermal Subsurface Flow and Compositional Transport Using Massively Parallel Computations *Mohamed F. El-Amin and Shuyu Sun, King Abdullah University of Science & Technology, Saudi Arabia*

Session 12 — Tuesday, May 17 — Hall-B

Drilling Operations (2) 09:30 - 11:15

Session Chairpersons: Naser Al Otaibi, Saudi Aramco
Wajid Rasheed, EPRasheed

09:30-10:00	Invited Speaker: Mr. Omar Al Husaini Manager, Offshore Drilling Department Saudi Aramco, Saudi Arabia	
10:00-10:25	SPE-SAS 1157	Successful Drilling and Deployment of an Open Hole Multi-Stage Fracturing System in a Deep and Hostile Sandstone Gas Reservoir *Abdul Halim Abdul Hamid, Mohamed Khalil and Shaker Al-Khamees; Saudi Aramco, Wael El-Mofty and Bryan Johnston, Packers Plus Energy Services; and Stuart Wilson, Schlumberger*

10:25-10:50	SPE-SAS 820	The Aramco Method – Its Drilling and Production Engineering Significance *Mohamed D. Amanullah, Abdulaziz Bubshait, John Allen and Darrell Foreman, Saudi Aramco*
10:50-11:15	SPE-SAS 874	Automated Technology Improved the Efficiency of Directional Drilling in Extended Reach Wells in Saudi Arabia *Roberto T. Kragjcek and Abdullah Dossary, Saudi Aramco, Waleed Kotb, and Abdelsattar Al Gamal, Wildcat Oilfield Services*

11:15-12:30	Keynote Luncheon Speaker (Main Hall): Mr. Ghassan Mirdad Worldwide Training Manager Schlumberger
	Lunch & Prayer Break
	Luncheon Generously Sponsored By Schlumberger

Panel Discussion — Main Hall

Unlocking Shale Gas from Middle East Reservoirs — 12:30 - 14:15

Moderator:

Mr. Samer S. AlAshgar
Manager, EXPEC Advanced Research Center
Saudi Aramco
Saudi Arabia

Panelists:

Mr. Matthieu Naegel
Manager, Unconventional Resources Research & Development Program
Total, France

Mr. Peter Richter
Vice President, Marketing and Technology
Unconventional Reservoir Group, Schlumberger, USA

Dr. David Kemakhem
Manager, Unconventional Gas Recovery Research
ExxonMobil, USA

Dr. Roberto Aguilera
Professor, Schulich School of Engineering
University of Calgary, Canada

Mr. Brian Gratto
Manager, Exploration Resource Assessment Department
Saudi Aramco, Saudi Arabia

14:15-14:30	Coffee Break

14:30 - 16:30 Poster Session Hall-B

Paper No.	Citation
SPE-SAS 658	A Simple Analytical Formula to Estimate Fracture Connectivity *Sait Ozkaya, Independent Consultant*
SPE-SAS 670	Study and field application of inorganic composite blocking agent with ultra-low density for water coning control in high temper *Qing You, China*
SPE-SAS 674	Experimental Investigation of Compositional Gas Injection Processes in Layered Porous Media *Abdullah AlAli, The University of New South Wales & Saudi Aramco, Mohammed AlHamdan and Yildiray Cinar, The University of New South Wales*
SPE-SAS 693	Application of High Performance Computing in Modeling Giant Fields of Saudi Arabia *Majdi A. Baddourah, Muhammed E. Hayder and Mohammad O. Sindi, Saudi Aramco*
SPE-SAS 698	An Accurate Prediction of CO2 Minimum Miscibility Pressure (MMP) using Alternating Conditional Expectation Algorithm (ACE) *Osamah Alomair, Adel Malallah, Adel Elsharkawy and Maqsood Iqbal, Kuwait University*
SPE-SAS 741	The Median Ratio and Near Wellbore Friction: Useful Proppant Admittance Criteria for Design and Placement of Safe and Effective Propped Hydraulic Fracture Treatments *Leon Massaras, Dimitri Massaras; Pangea Energy and Salim Al-Subhi; Petroleum Development Oman*
SPE-SAS 746	Importance of Production Logging Test Design for Inflow Control Completion Evaluation *Jon Eric Lauritzen, Ali Julaih, Ali Momin; Saudi Aramco, Noman Shahreyar and Dustin Young; Halliburton*
SPE-SAS 758	Raman Spectroscopy Yields New Discovery of Reaction of Acetic Acid with Calcite *Xiangdong Qiu and Frank Chang; Schlumberger*
SPE-SAS 766	Drilling Hazards Diagnosed and Solutions were Provided to the Northern Iraq Fields Utilizing Geomechanics *Jordan Gao, Martijn van Galen, Queena Chou, Blair Neil, Hamed Soroush and Hani Qutob; Weatherford*
SPE-SAS 768	Innovative In-situ Reservoir Stress Test Helped to Manage and Optimize Water Disposal under Fracturing Conditions in South Oman *Salem M. El Msallati, Koksal Cig and Pajang Priyandoko; Petroleum Development Oman*
SPE-SAS 788	Optimizing the Planning, Design and Drilling of Extended Reach and Complex Wells *Armstrong L. Agbaji, Baker Hughes*

SPE-SAS 800	Extending the Life of Giant Mature Oil Field by Innovative Cementing Technique *Nilo B. Neto, Schlumberger, Farid Hadiaman; Total, Amir Salehpour; Schlumberger, Hanifan Biyanni, Hery Setyawan and Muhammad Jamal; Total*
SPE-SAS 805	A New Nuclear Method to Locate Proppant Placement in Induced Fractures *Robert Duenckel; CARBO Ceramics and Harry Smith; Harry D. Smith Consulting*
SPE-SAS 807	Carbonate Wells Stimulations by Acidizing through Inflow Control Devices for Sredne-Sercheyusskoe Oilfield *Mikhail Chertenkov, Andrey Alabushin, Artur Abraov; Lukoil and Marat Nukhaev; Schlumberger*
SPE-SAS 824	When Should We Use Chelating Agents in Carbonate Stimulation? *M.A. Mahmoud, I.M. Mohamed, and H.A. Nasr-El-Din, Texas A&M University, C.A. De Wolf, AkzoNobel*
SPE-SAS 835	Simulation Study on Surfactant-Polymer Flood Performance in a Fractured Carbonate Reservoir *Nawaf SayedAkram, Saudi Aramco and Daulat Mamora, Texas A&M University*
SPE-SAS 860	Accurate Prediction of Pressure Drop in Two-Phase Vertical Flow Systems using Artificial Intelligence *Ahmad Al-Shammari, Saudi Aramco*
SPE-SAS 876	Surface Tension of Spent Acids at High Temperature and Pressure *Ramez Nasralla, Mashhad Fahes, Hisham A. Nasr-El-Din and Daniel Hill; Texas A&M University, USA*
SPE-SAS 890	A Novel 4-D Reservoir Simulation Workflow for Optimizing ICD Designs in a Giant Carbonate Reservoir *Byung Lee and Wahyu Hidayat; Saudi Aramco, Oloruntoba Ogunsanwo, Varma Gottumukkala, Edmund Leung and Feng Runa; Schlumberger*
SPE-SAS 908	Devonian Spore Assemblages from the Jubah, Jauf and Tawil Formations, South of Ghawar Field, Eastern Saudi Arabia *Abdulla M. Alghazi, Saudi Aramco*
SPE-SAS 918	New Approach to Classify Microporosity in Miocene Carbonate Reservoirs of Offshore Sarawak *Md Habibur Rahman, Bernard J Pierson and Wan Ismail Wan Yusoff, Universiti Teknologi PETRONAS, Malaysia*
SPE-SAS 933	Methods of Drilling Rate Increase, Near Bit Ejector *Sergey V. Evstifeev; Innoil LLC, Vladimir S. Evenko and Aydar F. Shakirov; Drilling Innovation LLC*
SPE-SAS 939	Step Change Technology for Running Tubulars *Lance Davis, Deep Casing Tools and Abdulaziz Al-Othman, Gotech*
SPE-SAS 956	Enhancing Well Testing Performance by Installing a Reliable Water Cut Meter Along with Coriolis Flowmeter *Ahmed Al Mutairi; Saudi Aramco, Babu Raman and Rami Helal; Weatherford*
SPE-SAS 963	Source Rock Characterization of the Hanifa and Tuwaiq Mountain Formations in the Arabian Basin Based on Rock-Eval Pyrolysis *Taqi Yousuf Alyousuf, Waleed Alghrbi, Rania Algeer and Azman Samsudin; Saudi Aramco*

SPE-SAS 995	A Novel Technique for Log-based Pore Volume Compressibility in Complex Carbonates through Effective Aspect Ratio *Vimal Saxena, Petroleum Development Oman*
SPE-SAS 997	A Novel Turbidity Based Method to Determine the Insoluble Residue in Polymer Samples *Anupom Sabhapondit, David Loveless, Phillip Harris and Jajati Nanda; Halliburton Energy Services*
SPE-SAS 1012	Facilities Planning using Coupled Surface and Reservoir Simulation Models *Muhammed E. Hayder, Ahmad Al Shammari and Alberto Munoz, Saudi Aramco*
SPE-SAS 1021	Sensitivity Analysis of Interfacial Tension on Saturation and Relative Permeability Model Predictions *Wael Abdallah; Schlumberger, Ardiansyah Negara; King Abdullah University of Science and Technology, Ahmed Gmira; Schlumberger, Weishu Zhao; Schlumberger and Johannes Buiting; Saudi Aramco*
SPE-SAS 1037	Petrophysical Evaluation of Shale Gas Reservoir: A Case study from Cambay Basin *Anil Tyagi, Ainul Abedeen and Tanmoy Dutta; Reliance Industries Limited , India*
SPE-SAS 1038	Intelligent Fields Data Management: Case Study *Naser A. Al Naser, Majed A. Awajy , Abdulsatar A Shaikh and Soliman Almadi; Saudi Aramco*
SPE-SAS 1041	Revisiting Dielectric Logging in Saudi Arabia: Recent Experiences and Applications in Development and Exploration Wells *Denis Philippe Schmitt, Ahmed Harbi; Saudi Aramco, Pablo Saldungaray; Schlumberger DCS Middle East, Tianhua Zhang, Schlumberger Dhahran Carbonate Research Center and Ridvan Akkurt, Schlumberger Boston Research Center*
SPE-SAS 1047	A New Approach to Determine the Filtration Properties of Drilling Fluid at Constant Differential Pressure *Salaheldin Elkatatny, Mohamed A. Mahmoud and Hisham A. Nasr-El-Din; Texas A&M University*
SPE-SAS 1053	Evaluating the ICD & MLTB Applications in Carbonate Reservoir Based on Sector Model to Develop a Green Field Off-Shore Abu Dhabi *Mohamed I. Afia, AbdelKader Allouti; ADMA-OPCO and Alexander Rincon; Schlumberger*
SPE-SAS 1059	Impact of Wettability Alteration on Recovery Factor *Abdulla A. Karimov, Azerbaijan State Oil Academy, Azerbaijan*
SPE-SAS 1060	Factors Affecting Production Behavior in Tight Gas Reservoirs *Waqar A. Khan, Shah AbduRehman, Agha H. Akram and Ammar Ahmad, Schlumberger*
SPE-SAS 1086	Log-Based Rock Property Evaluation – A New Capability in A Specialized Log Data Management Platform *Tosin Odunlami, Hamed Soroush and Paul Kalathingal, Weatherford and Jim Somerville, Heriot-Watt University, UK*
SPE-SAS 1089	Coiled Tubing Sand Clean Outs Utilizing BHA Technology and Simulation Software in Demanding Wellbore Geometries *Jeff Li, Emad Bedaiwi; Baker Hughes and Wenrong Mei, Saudi Aramco*

SPE-SAS 1094	Error Quantification of Dielectric Spectroscopy on Carbonate Core Plugs *Tianhua Zhang, Patrice Ligneul, Salah Al-Ofi, Benjamin Nicot, Fabrice Pairoys and Mahmood Akbar, Schlumberger*
SPE-SAS 1139	Underbalanced Drilling (UBD) as an Exploration Tool to Test Tight Gas Plays - an Example from the Empty Quarter, Saudi Arabia *Yousuf Al-Maashari, South Rub Al-Khali Company Limited, Leo Arseneault; Blade Energy Partners, Andrew Axon, Shell China Exploration and Production Company; Andreas Briner and Adrian Wevers; South Rub Al-Khali Company*
SPE-SAS 1160	Advanced Systems for Cementing Deep Sour Gas Wells *Zhijun Xiao, OPT Company and Hisham Nasr-El-Din, Texas A&M University*
SPE-SAS 1162	Success Criteria for Multi-Stage Fracturing of Tight Gas in Saudi Arabia *Zillur Rahim; Saudi Aramco, Stuart Wilson; Schlumberger Well Services, Wael El-Mofty and Bryan Johnston; Packers Plus Energy Services*
SPE-SAS 1216	Non-linear Model for Evaluation of Elastomer Seals Subjected to Differential Pressure *Moosa SM Al-Kharusi, Sayyad Zahid Qamar, Tasneem Pervez and Maaz Akhtar; Sultan Qaboos University; Oman*
SPE-SAS 1232	Stability of Local-Equilibrium Foam States in EOR Processes *Elham Ashoori, Dan Marchesin and William Rossen; Delft University of Technology, The Netherlands*
SPE-SAS 1241	Rheological Transition of Foam Flow in Porous Media *Mohammad Simjoo and Pacelli Zitha, Delft University of Technology, The Netherlands*
SPE-SAS 1244	Effect of Temperature, Asphaltene Content, and Water Salinity on Wettability Alteration *Talal Al-Aulaqi, Carlos Grattoni; Rock Deformation Research, Quentin Fisher, and Suleiman Al-Hinai; Petroleum Development Oman*
SPE-SAS 1245	An Innovative One Trip Optimized Wellbore Solution for Non-Cemented Liner, Wellbore Cleanup, and Sand Screen Placement Completion *David Duncan, Baker Hughes*
SPE-SAS 1258	Inaccessible Drilling Targets and Casing Exits Made Possible by the Alleviation of Excessive Torque and Drag: A Case Study *John E. McCormick, Weatherford*
SPE-SAS 1262	Elastic Properties of Emulsified Acids: Effect of Emulsifier Concentration and Temperature *Mohammed Sayed and Hisham A. Nasr-El-Din; Texas A&M University*
SPE-SAS 1272	Coreflood Study of Low Salinity Water Injection in Sandstone Reservoirs *Ramez A. Nasralla and Hisham A. Nasr-El-Din, Texas A&M University*

15:00-15:15	Prayer Break

15:15-16:30	Poster Session

Session 13 — Wednesday, May 18 — Hall-A

Well Completion — 08:00 - 09:15

Session Chairpersons: Mohammed Abduldayem, Weatherford
Jon Eric Lauritzen, Saudi Aramco

08:00-08:25	SPE-SAS 1117	Pioneer Application of Hydraulic Line Wet Mate Connect System in combination with a Pod ESP in Dual Lateral Intelligent Completion Well *Khalid S. Al-Mohanna, Khaled A. Kilany, Mark K Rooks, Iskandar X Riza; Saudi Aramco and Muhammad Shafiq; Schlumberger*
08:25-08:50	SPE-SAS 1270	Effects of Rapid Gas Decompression on Swellable Rubber and Common Oilfield Rubber Compounds *Dustin Young, Mohammed Al-Madlouh, and Peter E. Smith; Halliburton*
08:50-09:15	SPE-SAS 1264	New Swellable Elastomer Packer Design Improves Operations in 10,000 psi Differential Pressures in the Valhall Field in Norway *Tom R. Koloy, Kristian Andersen, Halliburton and Jeroen Nijhof, BP Amoco Norway*

Session 14 — Wednesday, May 18 — Hall-B

Production Operations (2) — 08:00 - 09:15

Session Chairpersons: Hasan Al Jubran, Saudi Aramco
Faisal Al Nughaimish, Saudi Aramco

10:00-10:25	SPE-SAS 1022	A Case Study: Production Management Solution "A New Method of Back Allocation using downhole Pressure and Temperature Measurments and Advance Well Monitoring" *Reda R. Abdel Rasoul, Cairo University, Egypt*
10:25-10:50	SPE-SAS 1238	Quantitative Corrosion Assessment with EM Pipe Scanner *Thilo Brill, Jean Luc L. Calvez, Cindy Demichel, Edward Nichols, and Fernando Zapata Bermudez, Schlumberger*
10:50-11:15	SPE-SAS 624	1st Successful Multilateral Well Logging in Saudi Aramco: Innovative Approach toward Logging Open Hole Multilateral Oil Producer *Ali Al-Momen, Saudi Aramco*

9:15-9:30	Coffee Break

Session 15 Wednesday, May 18 Hall-A

Drilling Operations (3) 09:30 - 11:15

Session Chairpersons: Fahad Al Mulaik, Saudi Aramco
Greg Conran, Schlumberger

09:30-10:00	Invited Speaker: Khalid Al Abdulgader Manager, Northern Area Oil Drilling Department Saudi Aramco, Saudi Arabia	
10:00-10:25	SPE-SAS 1082	Formation Damage Concern from Water-Base Mud Filtrate in Deep Gas Wells: Case Study *Joseph Ekpe, Andrey Kompantsev, Mohammad Emad, Ayman Ashoor, Fadhel Al-Khalifah and Ali Al-Ali, LukOil Overseas.*
10:25-10:50	SPE-SAS 972	Single-Sack Fibrous Pill Treatment for High Fluid Loss Zones *Qusai Darugar, Joseph Szabo and Dennis Clapper, Baker Hughes*
10:50-11:15	SPE-SAS 959	A New Approach to Drill Highly Depleted and Fractured Limestone Reservoir in Pakistan *Muhammad Asrar, Shahid Sabir, Weatherford, Saad Saleem and Syed Akhtar, Pakistan Petroleum Limited*

Session 16 Wednesday, May 18 Hall-B

Reservoir Engineering & Management 09:30 - 11:15

Session Chairpersons: Saud A. BinAkrish, Saudi Aramco
Noor M. Anisur Rahman, Saudi Aramco

009:30-10:00	Invited Speaker: Dr. Riyadh Moosa Manager, Corporate Technology Petroleum Development Oman	
10:00-10:25	SPE-SAS 683	Effective Well Placement and Trajectory Planning Approach through Collaboration Environment Tools *Hamad A. Alnaim, Ahmad M. Al-Baqawi, Ali H Habtar, Menhal A. Ismael and Arcides J. Araque Telemac; Saudi Aramco*

10:25-10:50	SPE-SAS 791	Recovering Flowing History from Transient Pressure of Permanent Down-hole Gauges (PDG) in Oil and Water Two-Phase Flowing Reservoir *Shiyi Zheng, London South Bank University and Fuyong Wang , Heriot-Watt University*
10:50-11:15	SPE-SAS 716	Multizone Well Testing with Downhole Tools in Extreme Sour-Gas Conditions *Florian Hollaender and Alan Salsman; Schlumberger, Fardin A. Neyaei, Richard Singleton, Abu Dhabi Gas Development, Fuad Al Badi and Efstathios Rigatos, ConocoPhillips*

11:15-12:30	Keynote Luncheon Speaker: Mr. Michael Bittar Senior Director for Dhahran Technology Center for Middle East & Africa Halliburton	Main Hall
	Lunch & Prayer Break	
	Luncheon Generously Sponsored By Halliburton	

12:30-13:00	Awards Announcement

Session 17 — Wednesday, May 18 — Hall-A

Reservoir Geology & Geophysics (2) 13:00 - 14:45

Session Chairpersons: Salem Al Shammari, Saudi Aramco
Khalid Al Areekan, Saudi Aramco

14:30-15:00	Invited Speaker: Dr. Aus Al Tawil Manager, Reservoir Characterization Department Saudi Aramco, Saudi Arabia	
15:00-15:15		Prayer Break
15:15-15:40	SPE-SAS 1028	Azimuth Preservation in Pre-Stack Time Migration using Offset Vector Tiles Robert Row and Mohammed H. Al Najjar; Saudi Aramco
15:40-16:05	SPE-SAS 1103	Application of Advanced Volume Interpretation (AVI) Workflows to Improve Data Quality for Rapid Interpretation Muhammad Badar, Saudi Aramco
16:05-16:30	SPE-SAS 783	Deblending The Simultaneous Source Blended Data; Is It Necessary? Shoudong Huo, Constantine Tsingas, Panagiotis Kelamis, Peter Pecholcs and Xu Hai, Saudi Aramco.

Session 18 **Wednesday, May 18** **Hall-B**

Advances in Improved Oil Recovery/Enhanced Oil Recovery (2) 13:00 - 14:45

Session Chairpersons: Sultan Al Enezi, Saudi Aramco
Larry Eoff, Halliburton

1300-13:30	Invited Speaker: Dr. Hisham A. Nasr-El-Din Petroleum Engineering Department Texas A&M University, USA	
13:30-13:55	SPE-SAS 1092	Cyclic Pressure Pumping (CPP): A Potential Recovery Method for Fractured Carbonate Reservoirs Augustine Ikwumonu, Keith Rawnsley and Solenn Bettembourg, Petroleum Development Oman
13:55-14:20	SPE-SAS 1218	Investigation of Polymer Flood Performance in High Salinity Oil Reservoirs Meshal Algharaib, Abdullah Alajmi and Ridha Gharbi, Kuwait University
14:20-14:45	SPE-SAS 722	Altering Sweep Profiles During Waterflooding using Near-Wellbore and Deep Reservoir Controls Loyd East, Leopoldo Sierra; Halliburton and Mohamed Soliman, Texas Tech University, USA

14:45-15:10	Prayer & Coffee Break

Session 19 **Wednesday, May 18** **Hall-A**

Petrophysics & Formation Evaluation 15:10 - 16:55

Session Chairpersons: Ahmed Al Harbi, Saudi Aramco
Derick Zurcher, Baker Hughes

15:10-15:40	Invited Speaker: Mr. Chuong Nguyen Senior Technical Professional and Petrophysicist Halliburton	
15:40-16:05	SPE-SAS 643	Multi-physics Approach for Aging Assessment of Carbonate Rocks Fabrice Pairoys, Benjamin Nicot , Tianhua Zhang, Patrice Ligneul, and Mahmood Akbar, Schlumberger

16:05-16:30	SPE-SAS 825	Cementation Exponent Estimation for Complex Carbonate Reservoirs using a Triple Porosity Model Ali Al Ghamdi, Roberto Aguilera and Chris Clarkson; University of Calgary, Canada
16:30-16:55	SPE-SAS 1219	Results from Pilot Tests Prove the Potential of Advanced Mud Logging (AML) Techniques Ton Loermans, Saudi Aramco, Farouk Kimour, Schlumberger and Alberto Marsala, Saudi Aramco

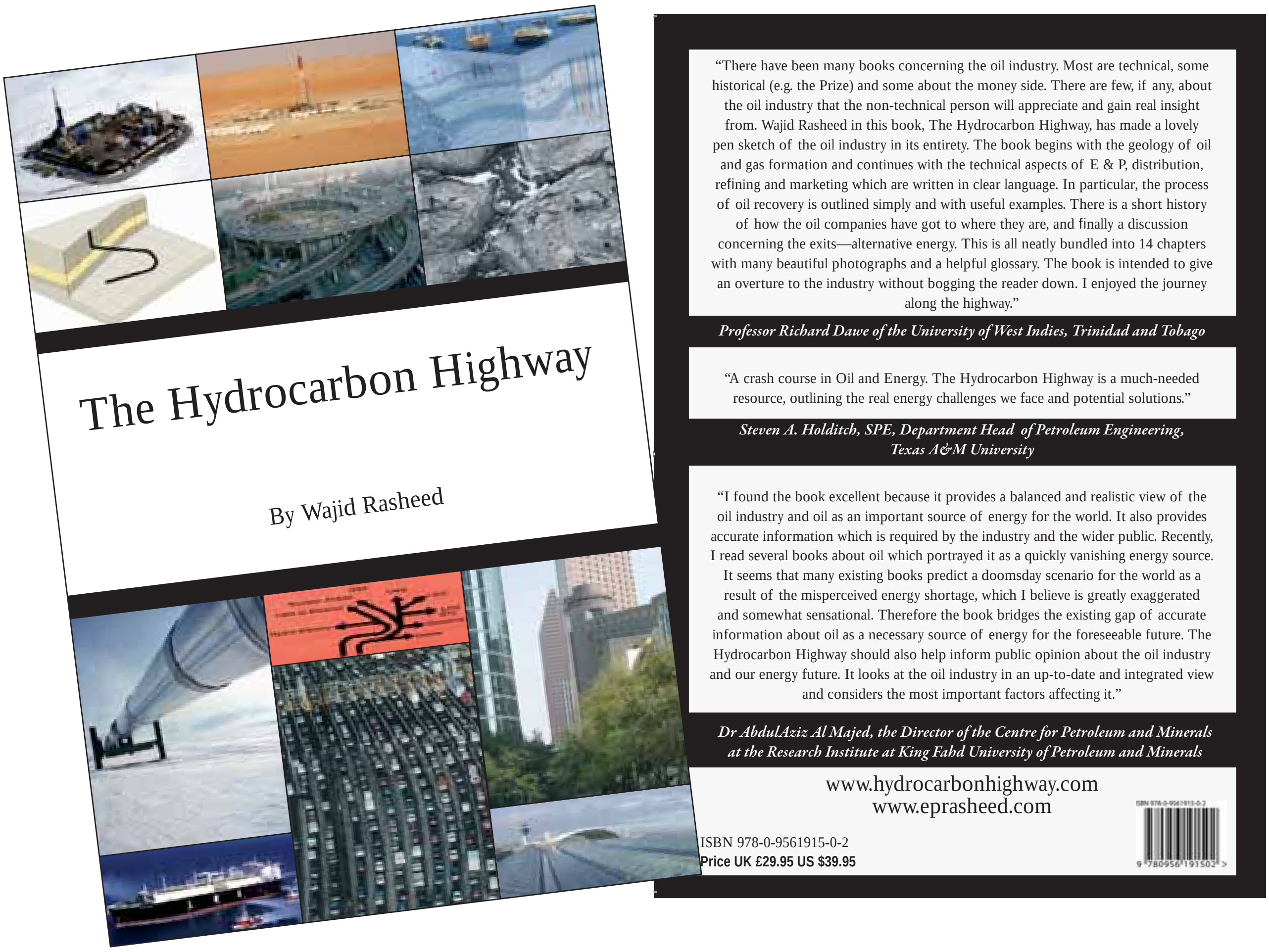
Session 20 Wednesday, May 18 Hall-B

Well Stimulation & Productivity Enhancement 15:10 - 16:55

Session Chairpersons: Murtaza Ziauddin, Schlumberger
Mohammad Al Khaldi, Saudi Aramco

15:10-15:40	Invited Speaker: Mr. Ernie Brown Director, Stimulation Domain Technology Schlumberger, USA	
15:40-16:05	SPE-SAS 725	A New Method to Determine Marble Provenance with XRD and Accessory Mineralogy Jack Lynn, Saudi Aramco
16:05-16:30	SPE-SAS 826	Opportunities/Lessons Learnt and New Technologies for Redevelopment of a Mature Field Ramiro Trebolle, Schlumberger; Victor Hugo Hamdan and Carigali Afzan Bin Mohammad, Petronas Carigali
16:30-16:55	SPE-SAS 685	Smart Combination of Technology Tools Resulted in Successful Rigless Stimulation on a Tri-Lateral Well, Case Study Ahmed Al-Zain, Abdulwafi Al-Gamber and Rifat Said, Saudi Aramco

Renewable Energy



In this chapter we consider renewable energy sources to identify what can effectively reduce oil and gas demand, not just theoretically, but in an environmentally friendly and cost-effective way[1]. But first, what of global warming and carbon emissions?

Modern economic growth and consumption has been concentrated in Western nations with oil, gas and coal providing most of the world's marketed energy; however, things are changing. Through carbon emissions capping, some Western countries have in fact limited the use of fossil fuels. Through outsourcing, some Western countries have also de-industrialised. The new growth economies are the 'BRICs' (Brazil, Russia, India and China) whose industries and populations need more energy and resist capping.*

Against the backdrop of global warming and resource scarcity though, how can 'uncapped' consumption be sustained?

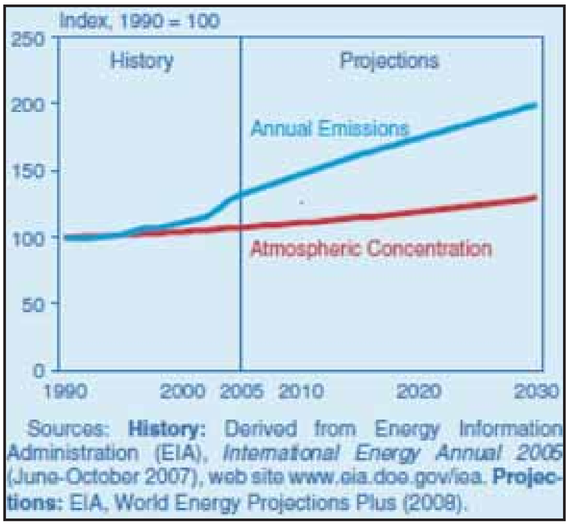


Figure 1 - Growth in Carbon Dioxide Emissions 1990-2030 (Source US EIA)

Global Warming

Since the 18th century and the Industrial Revolution, the temperature of the earth's lower atmosphere has been rising. Through 'the greenhouse effect', this has led to an alteration of the delicately balanced global climate system which is gradually being warmed. The greenhouse effect is so termed because levels of certain gases in the atmosphere have increased which means that more heat is retained on the earth[1].

In normal atmospheric conditions, sunlight reaches the earth passing through a layer of gases such as water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone. Here, infrared radiation reflects off the earth's surface but does not pass through the thermal layer as part of it is trapped to keep temperatures suitable to life, about 60°F (16°C). If it were not for this heat trap, the average temperature of the earth would be below freezing. The rapid industrialisation of the 18th century fuelled the demand for agriculture, land development and transport. As more fossil fuels such as coal were burned and as forests were cleared for development, ever greater quantities of Greenhouse Gases (GHG) were produced. Other types of gases such as chlorofluorocarbons (CFCs) also led to rising temperatures. Consequently, this resulted in more heat being trapped and rising air and sea temperatures[2,3,4].

Since the Industrial Revolution, volumes of CO_2 in the atmosphere have increased from 270 parts per million (ppm) to 370 ppm. This affects the natural CO_2 cycle that takes place between the atmosphere, oceans and forests. As greater quantities of CO_2 are generated, this leads to excessive loading of the natural cycle and

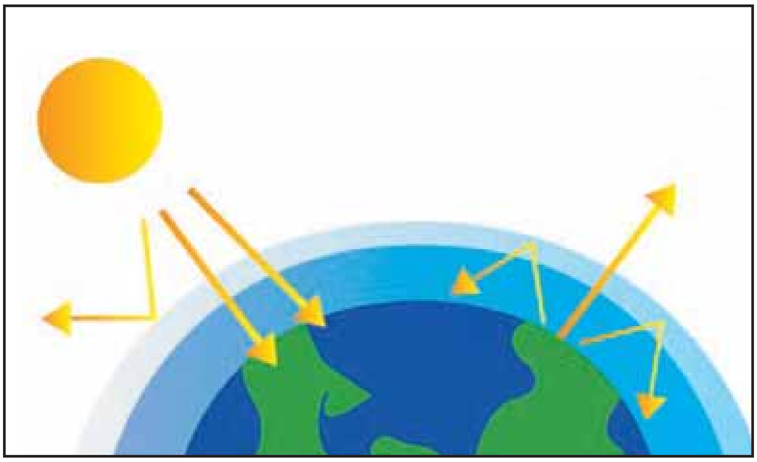


Figure 2 - Heat From the Sun is Trapped by the Gases in our Atmosphere

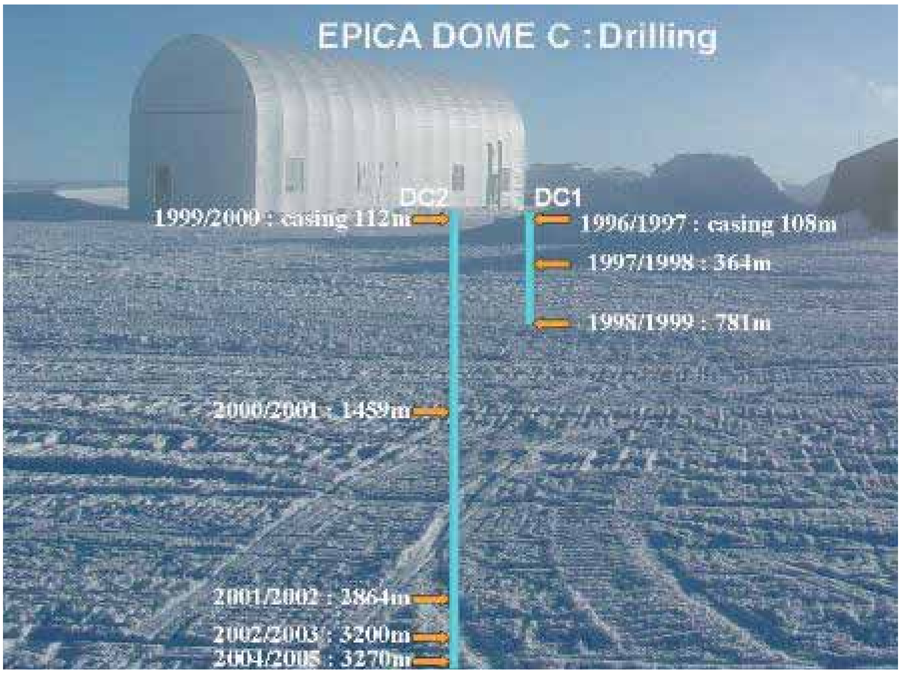


Figure 3 - EPICA

Figure 4 - Polar Ice Caps

a decreased ability of the earth's natural mechanisms (ocean and forests) to absorb CO_2. This gas, CO_2, has the greatest effect of GHGs and projections show that emissions will continue to grow. For CO_2 emissions to stabilise at 550 ppm, there would have to be a major reduction in the emissions complemented by new energy technologies that do not produce CO_2 at all; however, more than 80 per cent of today's energy demands are met by fossil fuels, which make replacement even more challenging.

Scientists have also started tracking changes in the polar ice caps. Since 1999, researchers working with the European Project for Ice Coring in Antarctica (EPICA) have drilled over 9,842 ft (3,000 m) into the Dome C ice, which corresponds to a geological timeline dating back nearly a million years. Over time, solids and fluids are trapped in the ice, and these provide insight into the atmospheric mixture of gases present across the timeline[5].

Researchers have found that CO_2 is now about 30 per cent higher than at any time, and methane 130 per cent higher. The rates of increase are absolutely exceptional: for CO_2, this is 200 times faster than at any time in the last 650,000 years.

Antarctic Climate Record

Some projected long-term results of global warming include: the melting of polar ice caps, a rise in sea level and coastal encroachment; the extinction of species as habitats disappear; higher intensity tropical storms;

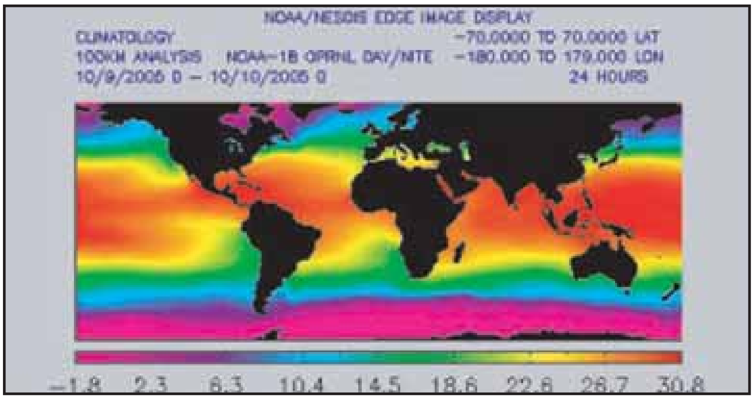


Figure 5 - Global Sea Surface Temperature Chart. Courtesy of the US National Oceanic and Atmospheric Administration (NOAA)

and, an increased incidence of tropical diseases. The Polar Research Institute has been conducting studies on physical glaciology and has noted that over the past 50 years the Antarctic and Greenland ice sheets are thinning near the coast due to accelerating glaciers and increased melting. Both are thickening inland due to increased snowfall. Overall, both sheets are close to balance, i.e. the snowfall gains are comparable to the coastal losses. This is leading to a rise in sea level. At present, the best estimate is that Antarctica and Greenland combined contribute 0.2 mm per year of the 1.8 mm per year global sea level rise[6,7,8].

Several polar ice cap trends have been identified, notably in the West Antarctic, where the ice sheet is losing ice mass because the glaciers are flowing too quickly, most likely due to warm ocean waters at their termini, and that Arctic sea ice area and volume have both decreased over the past 50 years or so.

Temperature's Up

Scientists keep track of global temperatures by registering air and sea temperatures. According to US environmental body figures, the global average temperature of the air at the earth's surface has warmed between 0.5°F and 1°F (0.3°C and 0.6°C) since the late-nineteenth century, while atmospheric temperature has risen 1.1°F (0.6°C), and sea level has risen several inches[9].

Little Boy

First noticed by fishermen in 1992, 'El Niño', which in Spanish means 'Little Boy' or the 'Christ-child', describes the arrival of a warm weather event coinciding with Christmas. La Niña means 'Little Girl' and is used to describe a cold weather event.

El Niño is an alteration to the ocean-atmosphere system, which starts in the tropical Pacific but has global repercussions. These include greater rainfall and flooding across the southern US and in Peru to drought and bushfires in the Western Pacific.

El Niño can be seen in sea surface temperatures in the equatorial Pacific Ocean, such as those shown in Figure 4, which were made from the National Oceanographic and Atmospheric Administration's (NOAA) array of moored buoys[10].

Kyoto

In order to combat global warming, the UN held a meeting in Kyoto, Japan, in 1997. This resulted in an international agreement to reduce emissions of GHGs by industrialised nations. Not all industrial countries, however, immediately signed or ratified the accord. In 2001, the US government announced that it would abandon the Kyoto Protocol. At the time, this was considered a major setback as the US generates 25 per cent of global GHGs. US President Barack Obama has already signalled a policy shift to ensure carbon emissions are reduced at the federal and state level. 125 other governments agreed to a binding international treaty which runs from 2005 to 2012. Further to this, many individual US states have committed to respecting Kyoto emissions levels at a local level[11].

Deep divisions exist as to what should occur post-Kyoto. The main objective will likely be to extend the treaty to include countries that have not currently signed such as the US, Australia and Russia. A major stumbling block is the exemption of so-called developing countries such as Brazil, China and India from Kyoto targets. These

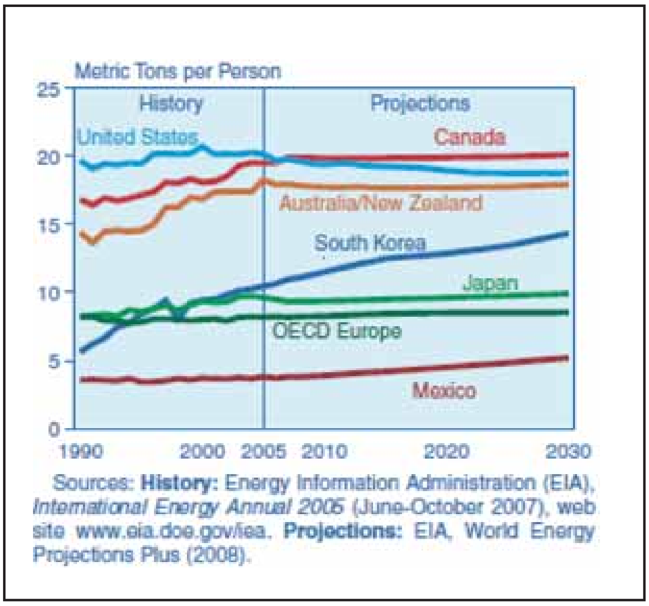


Figure 6 - Figure OECD Carbon Dioxide Emissions per Capita (Source US EIA)

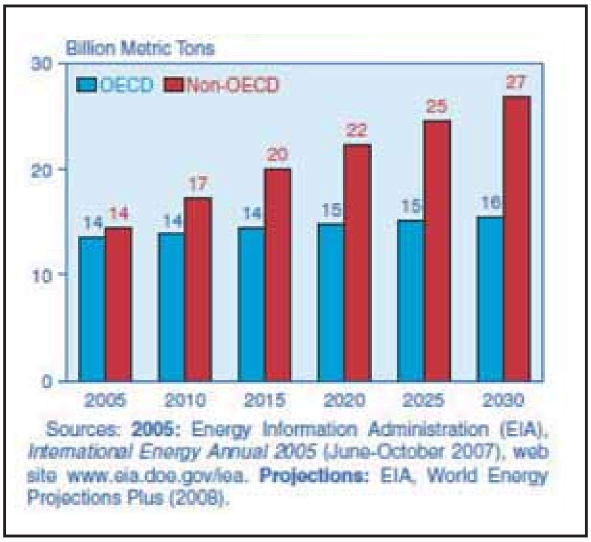


Figure 7 - World Energy Related Carbon Dioxide Emissions (Source US EIA)

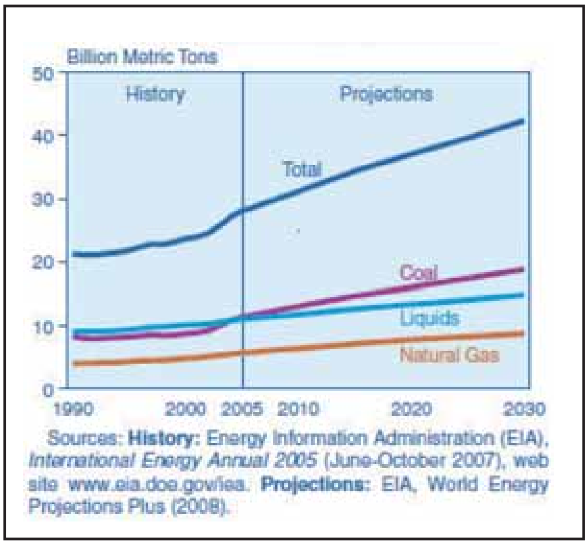


Figure 8 - Figure World Energy Related Carbon Dioxide Emissions by Fuel Type (Source US EIA)

countries have argued that Western development was responsible for much of the CO_2 emissions and this also led to these countries gaining developed status. The argument continues that applying CO_2 emission targets to developing countries would then hinder their progress. The counter-argument is that the location of industry makes no difference to emissions and they must be capped. Only time will tell whether consensus can be reached on this issue. The arguments and debates continue.

Contributors to Climate Change

It is recognised that the main contributors of global warming are the burning of coal and petroleum products, deforestation which increases the amount of CO_2 in the atmosphere, the production of cement which releases CO_2 and increased livestock production which increases the volumes of methane gas released in animal waste.

Sceptics argue that the climate cannot be modelled

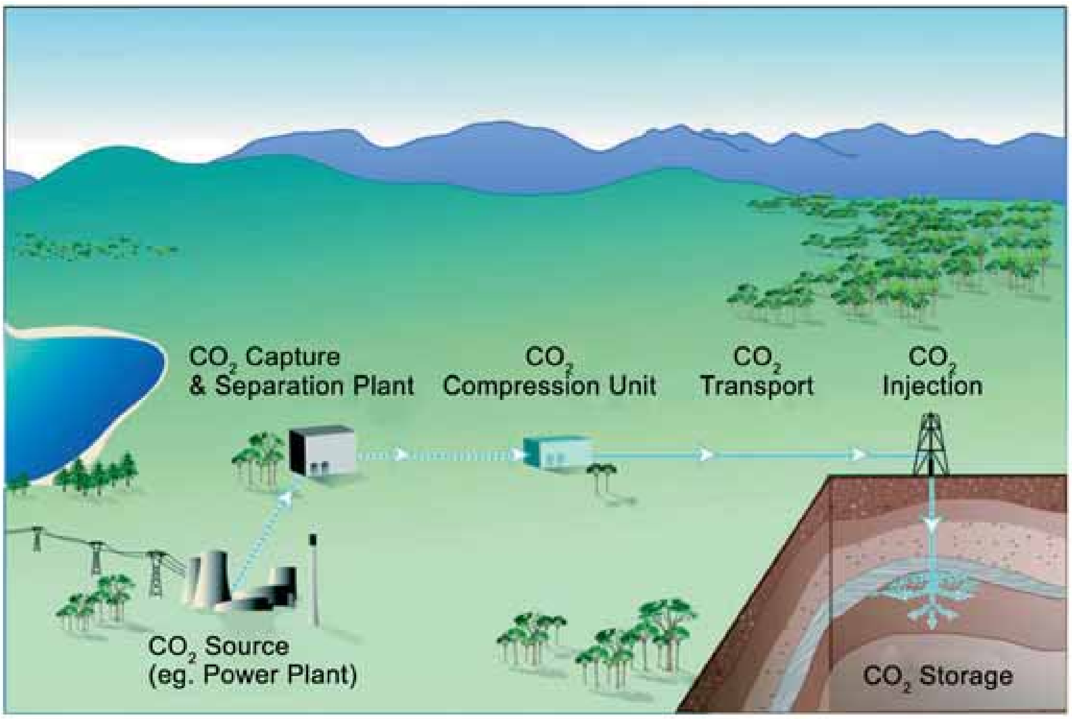


Figure 9 - Geologic Storage for Underground Carbon Capture and Storage (CCS) (Source: CO2CRC)

as it is too complex. They also contend that observed climate changes may be normal fluctuations in global temperature[12].

Despite this, most leading scientists agree that part of the observed warming is the result of human activity, and that the trend for warming has to be broken. This means finding other options to CO_2 emitting products and a raft of energy initiatives.

Energy Initiatives

Plans to reduce emissions include improving road transport mileage per gallon, reforestation projects and energy efficiency in construction and public transport systems.

More ambitious plans would include replacing fossil fuels with safe alternates, improving manufacturing and operational processes that generate CO_2, replacing CFCs with safe alternates and reducing deforestation[13].

Emissions

In order to reduce GHG emissions, several initiatives have taken place. These include improved manufacturing and operational processes that would otherwise emit CO_2 and reduction of the usage of emissions when energy is generated, i.e. selecting less harmful options such as Liquefied Natural Gas (LNG) which produces less GHG as it has a lower carbon content (see Chapter 3 What's In a Wet Barrel – Hydrocarbon Types).

Carbon Capture

These types of technology have a crucial role to play in reducing CO_2 emissions. Essentially, carbon capture or sequestration prevents CO_2 being released to the atmosphere. The CO_2 is captured and injected deep into geological formations which are known to have natural traps or seals. Carbon capture plants can be located close to power stations and oil and gas production facilities. To accelerate acceptance and reduce the costs of carbon capture, several carbon capture projects were launched focusing on carbon capture technologies and processes[14].

In terms of geologic storage, oil companies have already implemented CO_2 compression and injection into oil and gas reservoirs.

CO_2 is readily soluble in water and oil and miscible with gas. Where producing oil and gas reservoirs are contemplated, the injected CO_2 could be used to maintain reservoir production. On production, it would be separated from the oil, gas or water and re-injected. Such reservoirs are obvious choices as they already have a seal or cap rock in place (see Chapter 1: The Origin of Oil). In some gas producing provinces, as much as 10-15 per cent of the total gas in the reservoir is attributed to CO_2. In these cases, the CO_2 is not vented to the atmosphere, but is compressed and injected into the reservoir. CO_2 can also be injected into deep saline aquifers and unmineable coalbeds. It is estimated that large scale projects of this nature can take the equivalent of 200,000 cars off the road per year. Currently, several oil companies are involved in existing carbon capture projects, which are helping their acceptance from wider society[15].

It is now time to look at renewable energy sources starting with the array of gas technologies.

Gas Technologies

Gas has grown from being an unwanted hazard to the preferred energy for power generation. Illustrating this is the fact that Combined Cycle Gas Turbine (CCGT) technology has become the standard by which other power generation plants are measured. Here we look at the group of gas technologies – LNG, Gas to Liquids (GTL), Liquefied Petroleum Gas (LPG), Compressed Natural Gas (CNG) and gas hydrates. It is worth quickly noting that LNG and CNG are formed of naturally occurring fractions, principally methane and ethane; however, LNG is subjected to low temperatures and high-pressures to maintain its liquid state. CNG is subjected to compression alone as is LPG, which is principally composed of propane and butane[16].

LNG

LNG describes the liquid state of purified natural gas, principally methane and ethane, that has been subjected to temperatures of -160ºC (-256 ºF). LNG has been a major boon for natural gas because it adds cost-effective transportability of large amounts of natural gas where pipelines are impractical, e.g. across the ocean.

Over the past decade, the LNG industry has grown significantly with the creation of new markets for what was previously deemed stranded gas, which was too remote to be linked to existing pipeline systems but can now be safely transported to market.*

Typically, offloading facilities for LNG tankers require special berthing and unloading apparatus, with individual facilities varying in their handling capacities. Offloading involves the connection of unloading arms that pump the LNG onto storage tanks. These operate at atmospheric pressure and need to be especially well insulated to maintain the gas as a liquid[17].

LNG storage tanks are built with a double membrane wall using high strength steel nickel alloys to prevent heating. The outer wall membrane is made out of concrete. The revaporisation of LNG consists of thermal exchange processes which often use ambient seawater or other liquids to regasify the LNG before connection to pipelines.

LNG Markets

Comprising four main stages – E & P, liquefaction, shipping and storage and regasification – LNG projects require sizeable investments, often exceeding US $3 billion and highly specialised technical know-how. For these reasons, they are generally the preserve of majors.

The liquefaction facility is usually the highest cost-component within LNG projects.

Production, shipping, and re-gasification usually account for the remainder in roughly equal costs[18].

Process enhancements, technology advances and cost savings have reduced capital costs for liquefaction plants from US $600 per tonne of capacity in the late 1980s to about US $200 per tonne in 2001 and US $160.

LNG suppliers will sign contracts, typically 20 years, with buyers confirming the purchase before the projects go ahead. This explains why the LNG market has been the preserve of the major International Oil Companies (IOCs) and National Oil Companies (NOCs). The LNG global market is roughly divided into hemispherical lines, with the Western hemisphere consumers (the US and Europe) being supplied mainly by the Caribbean and North and West African exporters. The Eastern hemisphere countries of Japan, South Korea and Taiwan are mostly supplied by exports from Middle Eastern and Asia Pacific Rim countries.

LNG prices tend to follow a crude oil price index, but are higher in the Asia/Pacific basin than in the Atlantic Basin. In the US and Europe, LNG prices are more volatile following Henry Hub and seasonal demand fluctuations[20].

Exporting 38.48 Bm^3 in 2007, Qatar is the world's largest LNG exporter, with most of its exports split between Japan and South Korea. Qatargas is a joint venture between Qatar Petroleum, Total, Exxon Mobil and

Mitsui and Marubeni. It also produces approximately 60 thousand barrels per day (bbl/d) of condensate in addition to sulphur. Qatargas operates ten purpose-built LNG vessels, each with a capacity of 135,000 cubic metres [21].

Malaysia was the world's second largest LNG exporter, providing 29.79 Bm^3 of LNG in 2007. Most of its exports went to Japan who consumed 17.65 Bm^3. The major part of Malaysia's LNG exports is handled through its Bintulu Complex in Sarawak.

Indonesia is the world's third largest LNG exporter having exported 27.74 Bm^3 of LNG in 2007. Indonesia exported 18 Bm^3 to Japan which is the world's largest importer of LNG (88.82 Bm^3 total for 2007). Most of Indonesia's gas production centres on the Arun field in Aceh, the Badak field in East Kalimantan and the Natuna D-Alpha field (the largest gas field in Southeast Asia)[22].

Algeria exported 24.67 Bm^3, most of which went to France and other European countries. Sonatrach Algeria was the world's first major LNG producer when it began exporting LNG to Britain in 1965. The first liquefaction plant in the world was commissioned at Arzew in Algeria. Hassi R'Mel is the country's largest gas field (discovered in 1956) and contributes a quarter of Algeria's total gas production. Other Algerian gas reserves are located in the south and southeastern regions of the country[23].

Nigeria exported 21.16 Bm^3 and this was mainly imported by Spain and other European countries as well as North America[24].

Australia exported 20.24 Bm^3 and nearly all of it was imported by Japan. Most of Australia's production comes from the North West shelf[25].

Trinidad and Tobago exported 18.15 Bm^3, almost all going to the US. Trinidad's LNG started in April 1999 and now has the Atlantic LNG project in Trinidad and Tobago (BP, BG, Repsol and NGC)[26].

Russia is becoming the newest Asia/Pacific basin exporter. Its first LNG plant is under construction in Sakhalin Island off the country's east coast, with exports aimed at Japan.

Due to its position as the largest holder of gas reserves, it clearly has potential to develop its own reserves and supply growing demand.

Compressed Natural Gas (CNG)

Comprising purified natural gas (principally methane) that is pressurised at approximately 3,700 psi (255 bar) and stored in metal canisters, CNG is an efficient means of transporting fuel and fuelling transportation.

CNG and LNG are both delivered to engines as low pressure vapour. LNG can be used to make CNG which is a substitute for gasoline (petrol) or diesel fuel. It is considered to be environmentally 'clean' and is made by compressing methane extracted from natural gas[27].

Liquid Petroleum Gas

LPG is a highly portable and convenient fuel, which can be liquefied at relatively low pressures and high temperatures. This means it can be stored in metal canisters without the need to maintain subzero temperatures or the infrastructure of LNG. LPG contains varying ratios of propane and butane that have been compressed to form a liquid. Propane is used in propane gas burners at 203 psi (14 bar) and as butane in cigarette lighters 29 psi (2 bar).

LPG is a widespread fuel used in transportation (buses, cars), domestic usage (heating and cooking) and power generation. Both alkanes are used as propellants in aerosol sprays too. Many developing countries such as Brazil, India and Pakistan have very advanced markets for LPG, with many petrol pumps offering it as a petrol (gasoline) alternative[28].

Gas to Liquids

A promising technology with a bright future, GTL is a generic term for the catalytic processes that synthetically produce petroleum fuels from gas.

The most commonly known processes are based on the Fischer-Tropsch concept where very light hydrocarbon fractions are subjected to high temperatures and pressures in the presence of a catalyst.

This partly oxidising gas is then converted into liquid and fractionated in a manner similar to conventional refining, which achieves the desired blend of refined petroleum qualities within the limits of the process configuration. Companies such as Shell have successfully trialled GTL fuel in the UK and Germany with major car manufacturers. GTL will be a key bridging application for natural gas that will reduce the demand for high-demand light automotive applications[29]. Presently, GTL is prohibitively expensive unless volumes are high. It has been put forward as a way to commercialise stranded gas (where no viable market exists for the gas) as an alternative to flaring.

Gas Hydrates

Gas or methane hydrates are ice crystals that contain high amounts of methane. They are formed when water and methane are present in freezing or below freezing temperatures. Deep and ultra-deepwater conditions are ideal for the formation of gas hydrates which are most commonly found in sedimentary beds below the ocean. Gas hydrates are thought to be created as gas migrates from source rock and is crystallised on contact with freezing seawater. Gas hydrates are of future interest as the large amounts of trapped energy may be harnessed to generate usable methane. Not surprisingly, estimates vary as to global reserves and the technology for efficiently harnessing the hydrates has not yet been developed[30].

Nuclear Power

Principally used for the generation of electricity, nuclear power harnesses nuclear reactions to release energy. Other uses include submarine jet propulsion and heat.

Although the reactor is the heart of nuclear power generation, it represents a small part of the process. Uranium ore must first be mined and then converted into a manageable form known as 'yellowcake'. It is then processed to form uranium hexafluoride which must undergo sufficient enrichment before it is configured in shape and size to make reactor-specific fuel rods. These fuel rods remain inside the reactor until approximately 3 per cent of their uranium has undergone fission at which point the rods are termed 'spent'. The spent fuel is then moved to a cooling pool for five years or more where the decaying isotopes can be safely managed. After this period, the spent fuel is radioactively cool enough to handle and it is moved to dry storage casks or reprocessed[31].

The production of spent fuel is a major drawback associated with nuclear power generation. In fact, fresh spent fuel is so radioactive that less than a minute's exposure to it will cause death. Spent nuclear fuel becomes less radioactive over time, although it is still dangerously radioactive. There are over 400 nuclear reactors generating electricity in the world[32].

The pressurised water reactor is the most widely-adopted nuclear reactor technology The ongoing improvements in technology and performance have resulted in continuing reductions in the costs of power generation from nuclear stations.

CO2 is not released during the generation of electricity from nuclear power and it is a major factor in favour of nuclear energy. GHG emissions are very low across the whole life cycle and are comparable with the best renewables.

Globally, nuclear energy helps avoid the annual emission of over two billion tonnes of CO_2 that would otherwise be generated from fossil fuels. Nuclear generation is the largest single source of electricity in the European Union (EU). Of the 15 EU countries, those which have significant proportions of nuclear energy are consistently among those with the lowest CO_2 emissions[33].

Hydro Power

Hydro power systems generate electricity by releasing stored water in a controlled manner to drive turbines. In certain rural planning situations such as irrigation or flood barrier schemes, a hydroelectric power plant may be added with relatively low construction cost. 'Fuel' in the normal sense is not required to power hydroelectric plants which also have the advantage of zero GHG emissions. Hydroelectric plants tend to have a longer shelf-life than hydrocarbon generation plants, with some plants still generating power after a century's service. This is probably due, however, to the lack of harmful emission associated with hydroelectric plants as opposed to older hydrocarbon plants producing high emissions[34].

Low levels of rainfall or drought are the major limitation of hydro power. This can cause large reductions in power generation or may cause a complete halt. Environmental groups have stated that large hydroelectric projects can damage fluvial and marine ecosystems. The reservoirs of hydroelectric power plants in tropical regions may also produce large amounts of GHG. This is due to newly flooded and decaying plant material releasing methane once it enters the turbines[35].

Solar Power

Photovoltaic cells are most commonly seen in hand-held calculators where they provide energy through the use of solar power.

Applications of the technology are used on much larger scales where they are classed as being 'on-grid' or 'off-grid' and convert daylight into conventional electricity allowing everyday appliances to be powered.

The main advantages of solar energy are self-sufficiency,

Figure 10 - Solar Panels at Munich Airport (Source BP)

reduced carbon emissions and the sale of excess energy where connection to a grid exists, given adequate generating conditions.

Solar power, however, has limitations. The energy generation may not coincide with demand and consequently, power generated during off-peak periods must be stored so that it can be used effectively during peak demand.

On-grid systems can be found in urban areas and range from applications in governmental, commercial and residential systems where large numbers (50 or more) of panels are joined to create a solar farm generating a large enough amount of solar power that can be sold back to the electricity grid wholesaler[36].

Off-grid systems are mostly found in remote locations that are unconnected to wholesale electricity grids. This includes both villages and industrial applications such as in power generation or telecommunications.

The photovoltaic cell converts solar energy directly into electricity. Cells usually consist of several wafers of silicon or other semi-conducting material. The cell itself is a semiconductor diode that, depending on its configuration, can convert visible, infrared or ultraviolet light into direct current electricity.

When the cell is exposed to light, electrical charges generated in the silicon are conducted by metal contacts as direct current. Many cells are required to generate meaningful amounts of electricity and these are found in the form of glass solar panels[37].

Depending on the output required and other factors such as location, as many panels as can be configured to generate the required electrical output are required.

According to Shell, Copper Indium Diselenide or CIS refers to thin-film technology that may provide further cost savings as it is cheaper and more durable than silicon[38].

Large sets of photovoltaic cells can be connected together to form solar modules, arrays, or panels.

Major advantages of photovoltaics include the fact that they are non-polluting, only require real estate (and a reasonably sunny climate) in order to function and rely on solar energy which is unlimited in supply.

By making use of the photovoltaic effect, solar cells produce electricity. Absorbed light excites the electrons with negative electrons (-) attracted to the N-layer, and positive electrons to the (+). Once the circuit is closed, electricity is created.

Figure 11 - BP Experimental Fuel Cell Bus

Fuel Cells

Continuous electrochemical reactions form the basis for fuel cell energy. As well as offering high theoretical efficiency, fuel cells emit low or even zero levels of pollutants.

The fuel cell itself runs off hydrogen, but with the use of steam, reforming or partial oxidation can be powered by gas and GTL products. Fuel cells have the potential to be used in power generation and light automotive applications; however, the major limitation is the prohibitive costs associated with the technology.

The competitive target for fuel cells to compete with the internal combustion engine is US $50/kW. In stationary applications, a cost of US $1000/kW is seen as the long-term goal. Battery replacement can absorb very high costs per kW and lowest economic hurdle to entry. Today, prior to mass production and essentially in custom-build mode, fuel cells are somewhere in the US $2000/kW to US $20,000/kW range.

At between US $4000/kW to US $20,000/kW for stationary applications, they are well above a mature technology such as gas turbines at US $400/kW to US $600/kW. Even novel micro-turbines currently cost US $1000/kW to US $2000/kW. Mass production is seen as the solution to the high cost. In the meantime, funding from government agencies and companies interested in the technology has provided support for demonstration projects[39].

Biomass

Biomass is a catch-all term used to describe any solid, liquid or gas fuel that is derived from organic mass itself or its residues or byproducts. Each fuel type needs be distinguished if we are to understand the potential role each fuel has in replacing oil and gas demands. Liquids include ‘biodiesel’ that can be used in compression engines and are produced by modifying esters in vegetable seed oil. Liquids also include ‘biogasoline’ (ethanol) that can be used in spark engines and are produced from the fermentation of sugars. Finally, liquid fuels also include ‘bioGTL’ that can be used in both types of engines and are produced from GTL technology using biologically or man-made produced methane (biogas)[40].

Biogasoline

Biogasoline is the liquid biomass subset that contains ethanol, a well known alcohol fuel, but increasingly other fuels such as propanol and butanol.

Brazil is a major producer of sugarcane derived ethanol fuel, which is commonly available in roadside filling

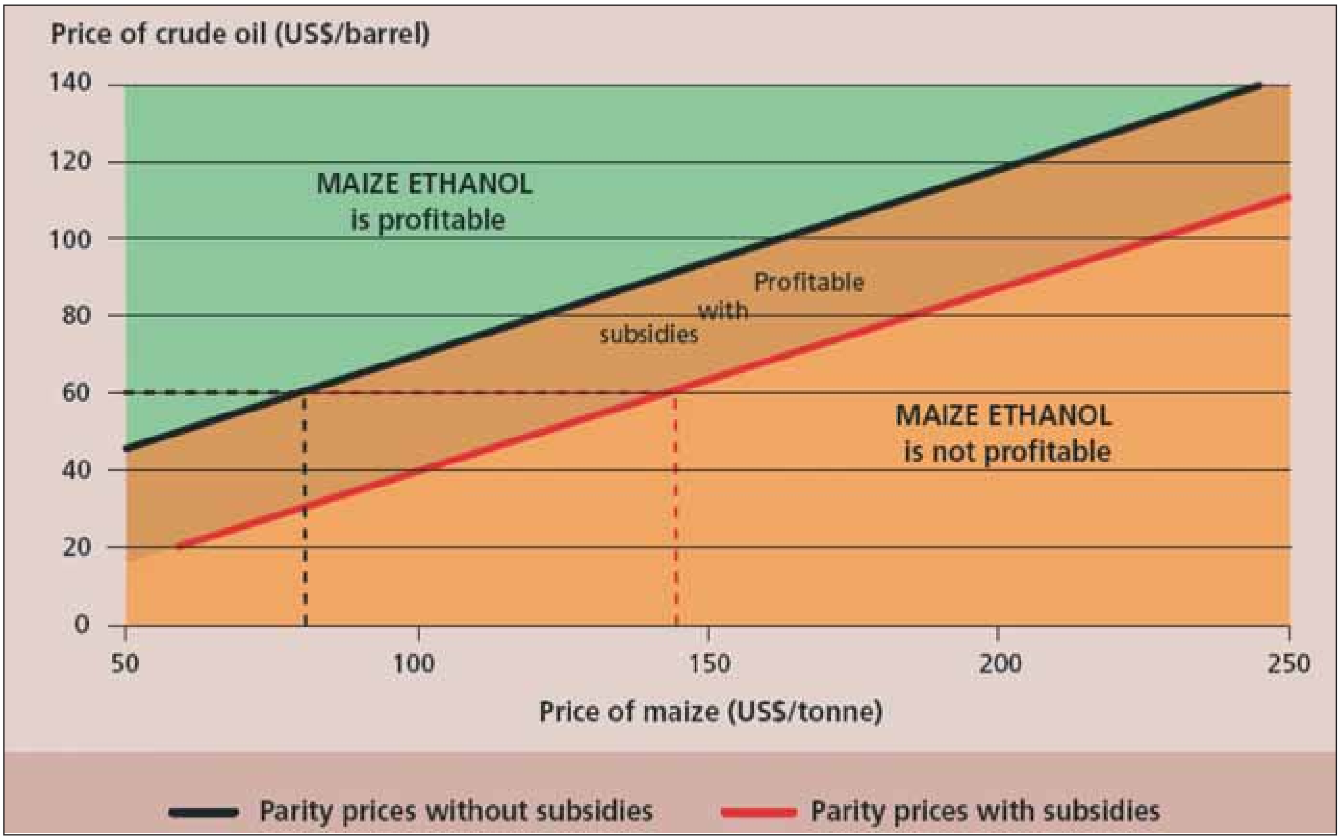


Figure 13 - Breakeven Prices for Maize Ethanol and Crude Oil with and without Subsidies (Source Petrobras)

stations along with petroleum spirit and LPG. The US also produces corn-based ethanol as a complement to petroleum rather than a substitute; however, ethanol replacement of petroleum is increasing. Detractors claim that its cost is greater than any value it brings to the equation[41].

Production

Ethanol can be produced from the fermentation of sugars or the steam cracking of ethane.

In the former, juice from sugarcane, corn or other feedstock is mixed with yeast and water at just above room temperature. Enzymes in the yeast break down the sugars into ethanol and CO_2. The CO_2 is vented to stop the ethanol from oxidising and becoming ethanooic acid (vinegar). Fractional distillation increases the yield of ethanol to 'fusel oil' or anhydrous ethanol (5 per cent water by volume)[42].

Ethanol can also be produced by the steam cracking of ethane in the presence of a strong acid catalyst. The reversible reaction is carried out at a moderately high temperature (i.e. 300°C [572°F]) and a high-pressure (i.e. 900 psi [62 bar]). The higher temperature and catalyst speed up the reaction. Although it is a faster and more continuous process, the disadvantage of the ethane route means further demands on oil and gas[43].

On average a tonne of sugarcane renders 65 litres of ethanol. The average cost of production, including farming, transportation and distribution, was US $0.31-0.35 per litre in Brazil, with a pump price of US $0.63-0.69 per litre in mid-2006. It is striking to trace these prices since 1999. At that time, the pump price of ethanol was US $0.09. Interestingly, this is a quadrupling of price over a seven year period. It is even more striking when we correlate the prices of ethanol and oil since 1999 to mid-2006. We see there is a quadrupling of price from US $10 to US $70. As a rule of thumb, the price of ethanol per litre is a tenth of the price of a barrel of crude oil[44].

Even though the differences between low-cost sugar producers such as Thailand, Pakistan, Brazil are not prohibitive, Brazil has the infrastructure to remain the lowest cost ethanol producer.

Figure 14 - Biomass Plant Using Organic Waste Spain (Source Linha 10)

It is highly probable that the sugarcane farming for ethanol production will increase as is illustrated by the demand/supply equation. This may have unwanted consequences and a balance will have to be struck as ethanol tends to become a cash-crop in certain replacement scenarios for gasoline; when oil prices are high, it displaces other crops[45].

Biogas

Biogas refers to biologically produced methane which is generated from any biomass feedstock, i.e. organic waste material such as wood pulp, animal residues or municipal organic waste. It is worth considering this process in detail as it can convert contaminants into commodities. Solid biomass includes the use of wood or dried animal dung for domestic cooking and heating. Liquid biomass includes animal or farming waste that has not been treated.

Methane gas is produced by bacteria during the decomposition of organic feedstock in a highly controlled process. The gas formed in this way is renewable and is a highly flexible form of generating gas as the feedstock can literally be any type of organic material.

The methane produced synthetically is often pure enough to pass directly through gas engines to generate direct electricity commercially or on a local scale. The biomass methane can also be used as the feedstock for the GTL process to create synthetic fuels. It is well-suited to electrical co-generation and waste treatment.

Biomass plants (also referred to as waste transformation plants) convert a potential contaminant (farmyard waste or other residues) into a marketable commodity (fertiliser).

Waste transformation plants allow the generation of electrical energy in a separate market from hydro-electric, gas turbine or nuclear based energy. Feedstocks include (but are not limited to):

- Biodegradable waste
- Sewage treatment sludge (primary or raw sludge and/or secondary sludge)
- Slaughterhouse waste
- Food waste
- Farm waste, and
- The organic component of mixed municipal waste.

Biomass plants are a sustainable clean and green energy process whose emissions and by-products (CO_2 and H_2O) are released to the atmosphere in a controlled manner. Ammonia and other by-products are re-incorporated within the fertiliser or, where required, are retrieved separately in liquid form. There is no release to the atmosphere.

It is worth noting that the biomass process has an application in any geographical location that presents a demand for electricity, the need to treat farmyard or other organic waste such as timber residues and offers a ready supply of natural gas. Locations within Canada, Brazil, Bolivia and other European countries would fit this category; however, factors such as average ambient temperature can dictate the overall energy efficiency and profitability of biomass plants. In the case of animal waste, in cold climates during the winter, energy is required to sufficiently dry the waste. Biomass plants, however, can act as a catalyst for the development of, and demand for, natural gas in separate markets from traditional consumer or industrial sectors. In countries where natural gas supply outstrips demand (Trinidad, Bolivia and Canada), co-generation plants can be an economical way of sustaining energy development as well as meeting growing electrical energy demand.

Biogas Description

A thermoelectric co-generation plant receives farmyard animal waste which is dried using natural gas fired ovens. Ducts are connected to combustion chambers enabling exhaust gases to be harnessed to drive turbines which generate electrical energy. Excess exhaust gases and heat generated by the system are regulated through a calorific control process and is used to dry the animal waste. After drying in the ovens, the waste has lost a high percentage of its water content and is characterised as stable—it will not ferment nor liberate toxic fumes. Effectively, this means that it has been converted into commercial fertiliser that meets environmental and legal requirements.

The process offers six major advantages:

- Generation of electrical energy
- Stimulation of natural gas demand
- Conversion of a potential contaminant into fertiliser
- Sustainability
- Controlled emissions, and
- Scalability (up and down) of plant size to meet market specific conditions.

This process is increasingly attractive as it meets energy needs in an environmentally friendly manner.

Waste Processing

This case study presents a co-generation plant based on technical considerations and Return on Investment (ROI) calculations. The quantity of waste that can be collected from various farms in the area is approximately 350,000 kg per day with a humidity varying between 65 per cent and 70 per cent. For the purposes of this study, 216,000 kg of waste would be treated per day. Final humidity is calculated to be approximately 20 per cent, a figure recognised by the waste treatment industry as the standard for compost or fertilisers. This plant runs for 8,000 hours per year due to the demand created by non-stop farmyard waste production[46].

The electrical and thermal co-generation plant uses natural gas-driven motors to dry waste from untreated levels of humidity (67.5 per cent to 20 per cent). The make and number of motors, however, can be modified to meet market specific needs. The gases liberated during the drying process are used as exhaust gases to drive engines which generate electricity. The dried waste is converted into marketable fertiliser for which there is ample demand.

Co-Generation Plant

The co-generation plant consists of the following equipment:

1. Natural gas engines
2. Waste pre-treatment system to condition waste before it is fed to the drying ovens. This maintains humidity and pH at controlled levels
3. Thermal drying ovens utilising the energy released from the exhaust gases and the water refrigeration units
4. Gas filters to absorb volatile particles and ammonium
5. Engine exhaust gas conduits and chimneys
6. Thermal exchange units to dissipate residual heat in the system, air coolant and cooling towers to dissipate unused residual heat from the thermal exchange units
7. Water circulation pumps
8. Electrical equipment (engine control unit, transformers etc. guaranteeing power output)
9. System and instrumentation management and control, as well as an anti-incendiary system
10. Ventilation and climate control of all areas

Not only is a potential contaminant treated and converted into a valuable commodity, but electrical energy is generated in a renewable process. Additionally, demand for natural gas is stimulated. This is important as gas reserves are increasingly being seen as a mobile commodity due to the liquefaction and storage innovations.

Wind Power

Using a combination of turbines and nacelles, wind energy can be used to create mechanical and electrical energy. Wind power has the major advantage of zero emissions, but has output and aesthetic limitations. Consequently, wind power generation needs power storage capacity so off-peak power generation can be used effectively during peak demand. Such power generation types are generally more expensive per unit of

Figure 15 - Wind Farm Coastal Area Spain (Source Linha 10)

electricity generated than base-load generators, so electricity suppliers prefer to minimise their use. Despite this increasing numbers of wind farms and standalone wind turbines are being set up by companies and individuals seeking their benefits.

Considered more appealing due to their unobtrusive offshore location, these wind turbines can be configured on a larger scale than their onshore counterparts. Offshore construction is, however, more complicated and expensive and such installations must withstand harsh conditions and subsea cables must be installed to transfer electricity.

Offshore turbines are also considered more efficient as higher average wind speeds are recorded over water, which offers less drag than land. Several European countries such as Spain and Denmark have implemented wind generation[47].

This review of renewable technologies helps us understand how easily or not oil can be replaced. In turn, this is the basis of the energy demand and supply equation. In the final chapter, this complex inter-play is unravelled so that we can envision how oil and gas applications may co-exist with other energy supplies. Can we actually live in a world that is not so dependent on oil and gas resources? Can we use other sources of energy to give us the same kind of lifestyles we have become accustomed to? What about our future generations – will they be leading a ‘greener’ life with less hydrocarbon use? How will that be possible?

It is now time to think about exits from the hydrocarbon highway – exits that will still allow us to meet energy demand but in a new, more environmentally friendly manner.

Can we turn away from hydrocarbons? One day of course, oil usage will decline. Yet, before that happens, the industry will continue to find, develop and produce oil more effectively. Why? The answer is simple – to provide an essential resource to mankind that will remain the preferred source of energy for the near future. To put it simply, despite oil price fluctuations, the demand for oil will continue to grow. The next chapter helps break down where all this demand comes from and the mass of products and processes that are dependent on oil.

References

1. The 2001 joint statement was signed by the scientific academies of Australia, Belgium, Brazil, Canada, the Caribbean, China, France, Germany, India, Indonesia, Ireland, Italy, Malaysia, New Zealand, Sweden, and the UK. The 2005 statement added Japan, Russia, and the U.S. The 2007 statement added Mexico and South Africa. Professional societies include American Meteorological Society, American Geophysical Union, American Institute of Physics, American Astronomical Society, American Association for the Advancement of Science, Stratigraphy Commission of the Geological

Society of London, Geological Society of America, American Chemical Society, and Engineers Australia.

2. "The Science Of Climate Change". Royal Society. May 2001.

3. Caldeira, Ken; Wickett, Michael E. (2005). "Ocean model predictions of chemistry changes from carbon dioxide emissions to the atmosphere and ocean" (PDF). Journal of Geophysical Research 110 (C9): C09S04.1–C09S04.12. doi:10.1029/2004JC002671. http://www.ipsl.jussieu.fr/~jomce/acidification/paper/Caldeira_Wickett_2005_JGR.pdf. Retrieved on 27 July 2007.

4. "New Study Shows Climate Change Largely Irreversible". National Oceanic and Atmospheric Administration. 26 January 2009. http://www.noaanews.noaa.gov/stories2009/20090126_climate.html. Retrieved on 03 February 2009.

5. "Eight glacial cycles from an Antarctic ice core". Nature 429 (6992).

6. Oerlemans, J. (2005-04-29). "Extracting a Climate Signal from 169 Glacier Records.

7. The Scott Polar Research Institute was founded in 1920, in Cambridge, as a memorial to Captain Robert Falcon Scott, RN, and his four companions, who died returning from the South Pole in 1912. When Scott's last words, "For God's sake look after our people" were made known to the British nation, the response was tremendous. Scott himself had emphasised the importance of science and from this plea, the Institute was born.

8. Stonehouse, B., 1990. North Pole, South Pole: a guide to the ecology and resources of the Arctic and Antarctic. London, Prion, 216 pp.

9. The U.S. Integrated Ocean Observing System (IOOS) is the U.S. contribution to the Global Ocean Observing System, or "GOOS." GOOS is a global system for sustained ocean observations designed to improve weather forecasts and climate predictions.

10. The moored buoys are deployed in the coastal and offshore waters from the western Atlantic to the Pacific Ocean around Hawaii, and from the Bering Sea to the South Pacific. The moored buoys measure and transmit barometric pressure; wind direction, speed, and gust; air and sea temperature; and wave energy spectra from which significant wave height, dominant wave period, and average wave period are derived.

11. Eilperin, Juliet (2005-07-02). "Climate Plan Splits U.S. and Europe". Washington Post. http://www.washingtonpost.com/wp-dyn/content/article/2005/07/01/AR2005070101915.html. Retrieved on 5 November 2006.

12. Hoyt, Douglas V.; Kenneth H. Schatten (1993–11). "A discussion of plausible solar irradiance variations, 1700–1992". Journal of Geophysical Research 98.

13. See Al Gore An Inconvenient Truth.

14. An interesting take on this is 'Biomass with capture: negative emissions within social and environmental constraints' by James S. Rhodes and David W. Keith.

15. Namely Shell, BP and Exxon Mobil.

16. The Global Liquefied Natural Gas Market: Status and Outlook Energy Information Administration, US EIA.

17. Society of International Gas Terminal and Tanker OperatorsWorld LNG Industry Standards.

18. US EIA LNG Energy Brief 2008.

19. Idem.

20. Idem.

21. BP Statistical Review 2008 (Source Cedigaz).

22. Idem.

23. Idem.

24. Idem.

25. Idem.

26. Idem.

27. "Fuels of the Future for Cars and Trucks", Dr. James J. Eberhardt, Energy Efficiency and Renewable Energy, U.S. Department of Energy, 2002 Diesel Engine Emissions, Reduction (DEER) Workshop, San Diego, California, August 25 - 29, 2002.

28. LPG offerings can be widely seen in these countries.

29. To enhance energy independence in the face of apartheid-related embargoes, South Africa satisfied most of its diesel demand with natural gas and coal derived diesel for decades and is still using the fuel in significant quantities. More recently, global concerns about energy supplies and costs and the environment have created interest in converting fuels to liquids elsewhere. For example, Shell markets diesel as a premium diesel blend in Europe and Thailand. See Shell booklet What is GTL?

30. Unconventional Gas Production: Hydrated Gas By James Mansingh and Jeffrey Melland. Hydrated gas reserves are currently estimated between 100,000 and 270,000,000 trillion standard cubic feet (TCF).

31. US EIA Office of Civilian Radioactive Waste Management.

32. US EIA data shows the World's nuclear industry having a total of 443 commercial nuclear generating units with a total capacity of about 364.9 gigawatts.

33. See EIA carbon emission.

34. It is common for hydro-electric plants to have their operational lives extended.

35. There is also the consideration of deforestation in building the hydro-electric plant.

36. Bolton, James (1977). Solar Power and Fuels. Academic Press, Inc.. ISBN 0121123502.

37. Balcomb, J. Douglas (1992). Passive Solar Buildings. Massachusetts Institute of Technology. ISBN 0262023415.

38. See Shell Booklet on Solar Power and CIS.

39. Hydrogen is commonly used during the electrochemical reaction. This raises a separate issue as to whether the hydrogen is chemically generated or reformulated from natural gas or methanol.

40. Sourced from Linha 10 renewable energy consultancy.

41. Despite this ethanol is increasing market share.

42. The fuel standard is higher and can be 99% reached by denaturing.

43. Ethanol produced by steam cracking is similar to Hydrogen derived from fossil fuels it is not a sustainable stream.

44. This is likely to increase in the future as ethanol becomes more commonly used.

45. This has not occurred in Brazil which has ample arable land.

46. Biomass Cogeneration As an aside, it is worth noting that electrical energy prices are country- specific; KWH is priced at 11.35 US cents in Bolivia compared to 5 US cents in Canada (Manitoba). Predicted oven dryer and engine performance is estimated at 62% and 38.6% respectively. These figures are based on past performance and take into consideration both scheduled maintenance and non-scheduled downtime.

47. Linha 10 database.