A Case for Nanomaterials in the Oil & Gas Exploration & Production Business

Matthew R.G. Bell

Shell Technology Ventures Inc.

200 North Dairy Ashford, Suite 7494

Houston, TX 77079

Tel: (832) 607-6660

Fax: (281) 544-2739

E-mail: matthew.bell@shell.com

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Abstract

While nanomaterials are frequently associated with alternative energy sources such as solar, fuel cells and the hydrogen economy, their application in the hydrocarbon extraction business is less frequently discussed.

The oil & gas industry faces a range of materials-related challenges, which lead to increased costs and limit the operating envelope of drilling and production technologies. This represents a significant market opportunity for nanomaterial-based solutions. However, barriers to entry and adoption are high, and collaboration between the oil industry and nanomaterial developers has to date been limited.

This paper recommends increased collaboration between oil producers and nanomaterial manufacturers, and identifies some critical factors for such partnerships to be successful.

Introduction

As readily accessible reserves become depleted, the oil and gas exploration and production (E&P) industry faces increasing technical challenges. Remaining reserves are found in deeper, more remote locations, and expose drilling and production equipment to more hostile conditions. The result is a steady increase in development costs and a perpetual need to push materials and technology to their operating limits.

Throughout the 1980s and 90s, upstream costs (exploration, development and production) showed a dramatic reduction from an average of US$ 27/bbl in 1981 (in 2002 dollars) to less than US$ 9/bbl in 1995[1]. Technological developments - such as horizontal and multilateral drilling - were the main drivers behind this drop. During the late 1990s, however, the trend was largely flat and in recent years costs have again begun to increase. Apart from the normal cycle of E&P costs, this can be attributed to the increasing maturity of producing fields, the declining size and increasing difficulty of new finds, more stringent environmental regulations, and increasing competition for access to reserves.

The average field size of new discoveries has declined from over 200 mln BOE[1] per discovery in the 1960s to less than 50 mln BOE in the 1990s[1]. Giant discoveries are perhaps not yet a thing of the past, but they are rare. Where giant field potential does exist, it is usually in deep-water frontiers or hostile regions in terms of climate and/or politics.

One of the underlying factors driving up development costs is the need to handle increasingly hostile fluids at higher temperatures and pressures. Remaining reserves, many of which were previously considered non-economic, are often contaminated with corrosive impurities, such as

[1] BOE = barrels of oil equivalent

carbon dioxide (CO_2) and hydrogen sulphide (H_2S). At elevated pressures or in the presence of water these contaminants can cause rapid degradation of steel components in the wellbore and in surface production facilities. The introduction of costly corrosion-resistant alloys, additional maintenance, and frequent repairs become necessary to avoid wellbore failure or loss of containment at surface.

The geothermal temperature gradient and geostatic pressure gradient mean that deeper drilling brings higher temperatures and pressures. Well depths in excess of 20,000 feet are becoming commonplace, with corresponding bottom hole temperatures exceeding 400°F (>200°C) and pressures above 20,000 psi. This is especially challenging for elastomeric and electronic components.

Drilling tools must also contend with tremendous shock loads (repeated shocks in excess of 100 G have been measured), abrasion, and thermal degradation due to heat generated by the drilling process. A 20,000 ft long drilling assembly can weigh as much as 1 million pounds and will be subjected to rotation, compression and tension as it is run in, used to make hole, and retrieved.

The material properties necessary to deliver enhanced drilling, wellbore, and production equipment are not foreign to the nanomaterials sector: abrasion and corrosion resistance, high strength-to-weight ratio, increased thermal conductivity, thermal and chemical stability, and so on. Nor is there any lack of commercial incentive: the E&P industry as a whole is expected to spend more than US$ 144 billion in 2004[2], with some major field developments costing in excess of US$ 10 billion each.

However, very few nanomaterial-based products have yet to appear in the E&P technology basket. This can be attributed to a number of factors:

- Lack of innovation in the E&P sector

- Barriers to entry and adoption in the E&P sector
- Perceived cost and risk
- Lack of awareness of E&P challenges in the nanomaterials sector

The remainder of this paper will discuss these factors in more detail, and propose a strategy for increasing the penetration of nanomaterials into the E&P sector.

A Lack of Innovation

In recent years the E&P sector has adopted a stringent cost focus, continuously striving to increase efficiency and drive down supply costs through aggressive contracting and supply chain management. As a result, new technologies that add to the cost of E&P operations face an uphill battle for acceptance.

The costs and risk associated with new technology development have been forced onto oilfield service providers, with operating company R&D budgets falling 50% between 1992 and 2002. In the face of low margins and slow uptake, service companies have constrained their developments to incremental enhancements, disruptive innovations being an unwelcome threat to established product lines.

Most of the true innovation in the E&P sector is taking place in small, entrepreneurial ventures, either trying to introduce genuine inventions or harvesting and adapting technologies matured by other industries. Many such ventures fail to survive the slow and painful journey from start-up to oilfield supplier and their ideas are lost or shelved.

Barriers to Entry and Adoption

For technologies that do make it to proof-of-concept, the path to commercial success is far from easy. The E&P sector is slow to accept and adopt new technologies. The average time from idea to commercial sales exceeds 20 years; compare this to the consumer goods industry at 6 years, pharmaceuticals at 8 years, or the telecommunications industry at 11 years[3].

This risk-averse attitude is in large part due to the considerable cost of failure. The cost to drill a well ranges from $ 0.5 to 100 million, with fully loaded rig costs running up to $ 500 thousand per day; any delay or upset requiring remedial activity can rapidly lead to considerable cost over-run. Furthermore, any delay to the completion of a well or downtime associated with remedial activities leads to lost production, something E&P companies cannot accept in the face of stiff production targets. The introduction of an unproven technology – which inevitably carries a higher risk of failure than proven alternatives – is thus difficult to justify, even when the incremental value of successful deployment is significant.

However, the application of nanomaterials need not be limited to revolutionary technologies. In some cases significant benefit could be derived by simply replacing equipment fabricated from conventional materials with a nanomaterial-based equivalent – much easier for the customer to accept than a radical alternative. Having established the viability of nano-based products using such a displacement approach it should then be easier to introduce other, more fundamentally different technologies as the industry becomes more generally tolerant of nanomaterials.

Examples of incremental technology improvements that may be most straightforward to implement are: chemical and abrasion resistant coatings for drilling assemblies, production tubulars, and valves; alloys containing nanomaterial for increased strength at reduced weight, and improved metallurgical properties; nano-scale chemicals to control fluid losses during drilling or provide flow assurance in pipelines; the use of energetic nanomaterials in perforating devices; the use of nanomaterials to deliver chemical treatment to the wellbore or into the producing rock formation.

No Room for Rocket Science?

Nanomaterials are widely perceived as expensive and exclusive, fit for the silicon wafer laboratory but not for the rough-and-ready oilfield. While nanomaterial developers continue to pursue the cutting edge of science, some of the technologies needed to make a difference in the E&P sector are relatively mature. Basic coatings and alloys - while not glamorous enough to attract academic research funding - could substantially extend the performance envelope of oilfield components. This is significant for several reasons:

- Raw material and process costs to implement these basic nanomaterial applications have fallen dramatically in recent years, such that they are becoming competitive with oilfield alternatives (e.g. exotic alloys)
- There is a growing body of academic and industrial expertise to support such applications, reducing the time and effort required to develop and perfect the product.
- Such applications have already been proven in more cost-tolerant industries, such as aerospace and military. The migration of mature technologies into lower cost environments such as the automobile and process industries has already begun.
- Academic and, to some extent, industrial focus is on cutting-edge developments and products. Large corporations are offering substantial rewards for solutions to high-tech problems. As a result, few academics and entrepreneurs are looking at deploying mature nanotechnologies into broader markets such as oil & gas. Their expectation is

> that established industries will automatically adopt such technologies as they become cost-competitive with current practices, motivated by the performance gains that nanotechnology will deliver. However, as a result of its lack of innovation and risk-averse attitude, the oil and gas industry continues to view nanotechnology as a 'thing of the future'.

While many possibilities exist for the application of mature nanotechnologies, there is also tremendous scope for more radical step-change technology. Nanobots, designer molecules and biomimetic devices can all be linked to visions of the future oilfield, but it will be some time before such technologies can be harvested from higher-cost industries willing to sponsor their development.

A Lack of Awareness

While the E&P sector may be either ignorant of or turning a blind eye to nanomaterial opportunities, there is a corresponding lack of awareness of E&P challenges among the nanomaterial community.

Recent conversations at a major nanotechnology conference revealed that most nanotech CEOs and CTOs were entirely unaware of the E&P opportunity. Some had identified the sector as having future potential, but few were actively pursuing product developments. The consensus among those interviewed was that alternative energy (such as solar), energy storage, hydrogen generation and storage, and fuel cells were the primary opportunities in the energy sector.

The only E&P application specifically mentioned by attendees was the use of nano-diamond coatings to enhance the performance of drill bits. This was described in the conference literature as a “mundane” application, apparently overlooking the fact that drill bits face stiffer performance and environmental challenges than components of the international space station!

Such a lack of awareness is understandable because E&P companies have made very little effort to inform the nanotechnology world of their plight. E&P investment in nanotechnology development pales into insignificance when compared to other industries. Notable exceptions include ConocoPhillips spinout SouthWest NanoTechnologies, set up in conjunction with Oklahoma University, and a number of investments made by Chevron Texaco’s technology ventures group[4]. In general though, the industry is set to watch-and-wait, keeping an eye on developments without actively pursuing commercial possibilities.

This may be the major reason why nanotechnology has thus far made only a limited entry into the E&P market. Typical nanotechnology start-ups forge partnerships with industry at a very early stage, often prior to spinout from the university lab. In the absence of such collaboration, the focus on solving E&P challenges will likely remain limited.

The Size of The Prize

Before discussing what might be done to improve this situation, let us briefly examine the order-of-magnitude benefits that might accrue to E&P companies and nanotechnologists prepared to work with them.

The oil and gas industry is expected to drill in excess of 75,000 wells worldwide during 2004[5]. Drilling and completion expenditure is forecast at $36 billion. Total E&P expenditure in 2004 is expected to top $ 144 billion[2].

Over the next five years it is expected that 15,000 offshore wells will be drilled worldwide, at a total cost of some $189 billion. Of these wells nearly 4,500 will be exploratory, costing $75 billion, and around 10,500 will be development, costing $114 billion. The proportion of wells drilled in deepwater is expected to increase to around 17% of all wells drilled by 2008, with $56 billion (30%) of the total forecast expenditure on drilling and completion being directed toward deepwater wells[6].

Within these costs, a significant proportion can be attributed to the materials used to construct and maintain wells and facilities (though no explicit value is consistently reported in the literature). A further tranche may be assigned to activities made necessary by the inadequacy of materials in use, such as preventative or critical maintenance, and repair or replacement.

The mean time between failure of oil and gas well components plays a critical role in determining operating costs. Downhole pumps, for example, may experience average run lives as low as 12-18 months in difficult environments due to overheating (poor thermal transfer properties), erosion (due to solids in the production stream), chemical attack (corrosion, embrittlement, elastomer degradation), or mechanical failure (insufficient strength, vibration). Technologies able to mitigate these factors and prolong the operating life of a critical well component can generate substantial business value and open up a large market.

Given the scale of the industry as a whole, it is apparent that even products targeting only a subset of this activity can expect to sell large volumes if significant market penetration can be achieved. Net cost reductions amounting to only fractions of one percent will deliver millions of dollars in bottom line value on a continuous basis.

Strategic Changes to Bring Nanotechnology to the E&P Sector

For the E&P and nanotechnology industries to collectively tap into the under-exploited potential of nanomaterials a deliberate effort must be made to educate and collaborate.

Both E&P operating companies and service providers need to engage nanomaterial developers in seeking solutions to current material-constrained challenges. They must also share their longer-term visions for next-generation oilfield technology, so that the potential role of nanotechnology can be objectively assessed.

Equally, nanotechnology proponents should actively engage E&P companies to identify business opportunities where the benefits of nanomaterials can be brought to bear. This should not be constrained to cutting-edge nanotechnology, but should also seek to transfer mature technologies proven in other industries.

None of the foregoing will be possible without investment. Given the difficulties associated with the commercialization of new technologies in the E&P market, progress will only be made if E&P operating companies enter into commercial partnerships with nanomaterial developers at an early stage. This may require seed investment at a much earlier stage than would typically be considered for E&P technologies. Once again the bridge needs to be built from both sides: E&P companies need to identify funds for nanotechnology development and nanotechnology companies must approach them with credible investment opportunities linked to specific solutions to oilfield challenges.

Furthermore, if E&P companies truly wish to harness the potential of nanotechnology, they should consider posting significant rewards for solutions to their most acute problems. This approach has proven effective in other sectors, and would allow the E&P industry to compete with other, more glamorous businesses for the attention and intellectual capital of nanotechnology developers.

As with any scientific frontier, both risk and reward will be greatest for the early movers. The operational and business advantages to be gained by having early access to nano-enabled products are significant, but there will be many failures for every success. It is certain that many of the multitude of nanotechnology startups that have blossomed in recent years will fail to achieve commercial success. Similarly, the E&P industry and its chosen nanotechnology partners should expect many of their investments to fail. This is a necessary risk associated with gaining access to the only currently emerging scientific field likely to offer solutions to the material challenges facing the E&P industry.

Summary

The oil & gas exploration & production industry faces increasing technical challenges to develop deeper, more remote reserves as existing assets mature. This results in steadily increasing costs and a perpetual need to push materials and technology to their operating limits.

The technology must contend with corrosive impurities, high temperatures and pressures, shock loads, abrasion, and other hostile environmental conditions. The material properties needed to meet such challenges are familiar to the nanomaterials sector, yet very few nanomaterial-based products have entered the E&P market. This can be attributed to a lack of innovation, barriers to entry and adoption, perceived cost and risk, and a lack of awareness of E&P challenges.

The introduction of unproven technology, which inevitably carries increased risk, is difficult to justify to risk-averse E&P customers. However, simply replacing conventional materials with a nanomaterial equivalent could already deliver significant benefit. Examples include coatings, alloys, energetics, and nano-scale chemicals in drilling fluids and well treatments. As E&P acceptance matures, there will also be significant scope for more radical step-change technology.

Most nanotech CEOs and CTOs are unaware of the E&P opportunity, in part because E&P companies have made little effort to inform them of their needs. The E&P industry has adopted a watch-and-wait philosophy, continuing to view nanomaterials as something for the future.

A deliberate effort is needed to educate and collaborate, in order for the E&P and nanotechnology industries to collectively capitalize on this significant business opportunity. E&P companies need to engage nanomaterial developers in seeking solutions to material-constrained problems. Nanotechnology proponents need to actively engage E&P companies to identify potential nanomaterial applications.

To facilitate this, E&P companies need to enter into partnerships with nanomaterial developers at an early stage. They must identify specific funding for nanomaterial development and should consider posting sizable prizes for solutions to the most acute problems. Both sides need to accept that some necessary investment risk must be taken to bring nanomaterials into the E&P market.

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