SPECIAL REPORT

High Performance Anti-Corrosion and Anti-Wear Cladding Pipe Technology

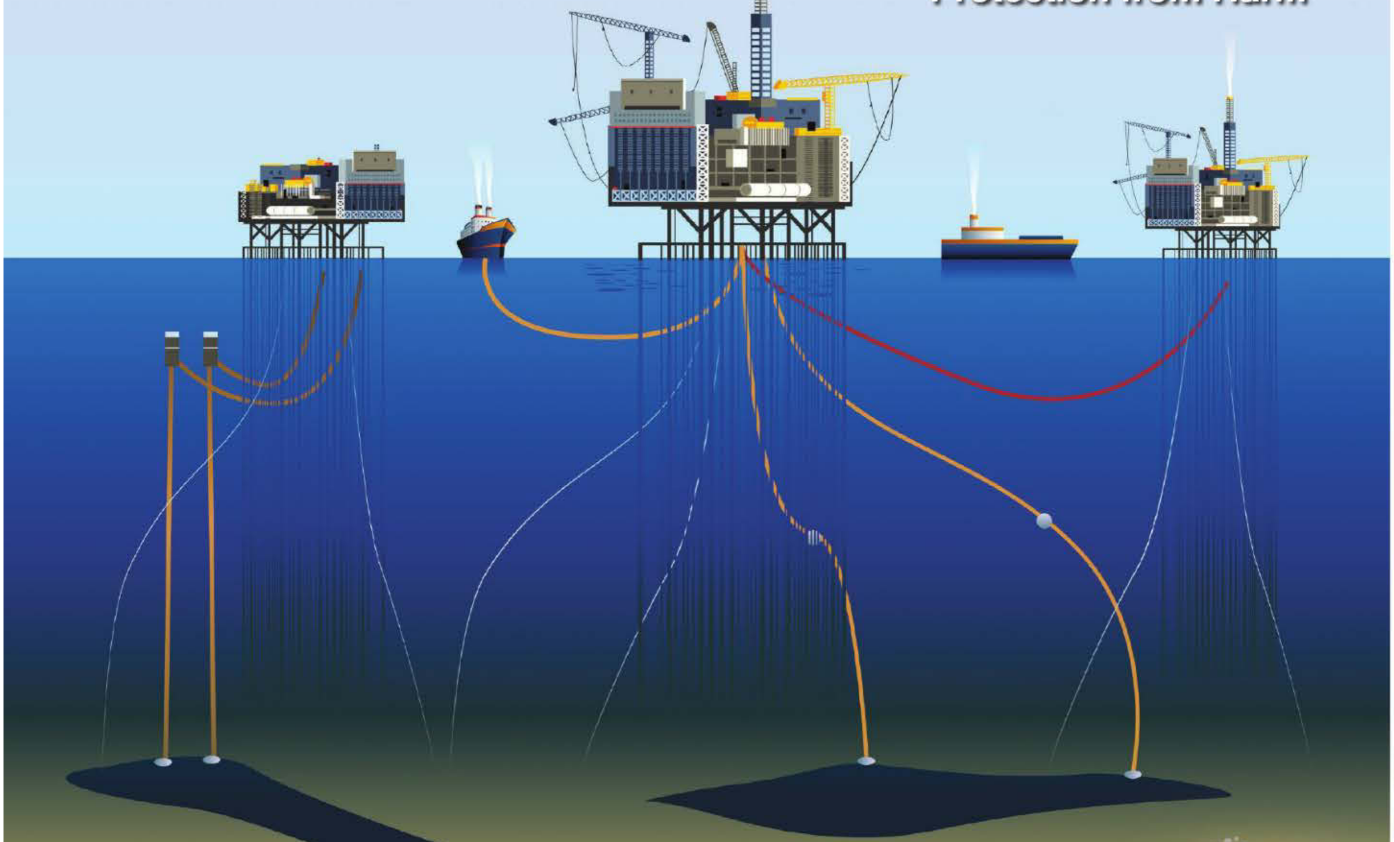
MesoCoat Develops Seamless, Corrosion-Resistant Clad Pipes for Deepwater and Onshore Oil and Gas Applications

A Key Component in a Vital Sector

An Economic Asset

A Hostile Environment

Protection from Harm



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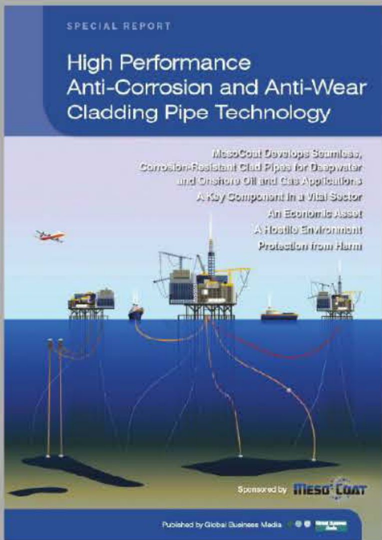

Published by Global Business Media

Global Business Media Limited
62 The Street Ashtead Surrey KT21 1AT
United Kingdom

Switchboard: +44 (0)1737 850 939
Fax: +44 (0)1737 851 952
Email: info@globalbusinessmedia.org
Website: www.globalbusinessmedia.org

Publisher
Kevin Bell

Business Development Director
Marie-Anne Brooks

Editor
John Hancock

Senior Project Manager
Steve Banks

Advertising Executives
Michael McCarthy
Abigail Coombes

Production Manager
Paul Davies

For further information visit:
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Cover image – Snorre B, Statoil/Harald Pettersen

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Foreword

The oil and gas industry works to a long timescale. From commencing exploration through discovery, commercial drilling, production and continual operation until final decommissioning can be well over 50 years. Not many businesses plan five years ahead let alone five or more decades! Add the massive cost of exploiting reserves, the challenges in getting products to market with the over-riding imperative to be safe and to minimise the environmental impact of an essentially extractive industry and it can be seen why the requirements of this business are so demanding.

This Special Report opens with an article that describes a new process for producing seamless, metallurgically-bonded, corrosion-resistant clad pipes, developed by MesoCoat Inc. It goes on to describe the cladding process and how, improving technology is allowing economic production from corrosive and deepwater reserves of oil and gas, and sets out details of various pipe solutions for exploration and production of corrosive oil and gas reserves. Compared to competing mechanical-lined (bi-metal) pipe and roll-clad and welded pipe, MesoCoat's CermaClad™ clad pipe provides a true metallurgical bond tested to over 70,000 psi tensile and 31,000 psi shear strength in a seamless (weld-free) 12 meter pipe product.

Consider how much of the oil and gas reserves that remain to be exploited are offshore; thousands of feet below the earth's surface which is itself under thousands of feet of water. And what product is left to be won is often of a lower quality which means more corrosive.

Is it any wonder then that this industry values quality and longevity in the engineering it employs to match the lifespan of its exploitable assets. It is not surprising that deepwater pipelines are a focus of much quality consideration. Subject to numerous threats and strains, but especially vulnerable to corrosion, any loss in pipe surface quality (external or internal) can significantly compromise the integrity of the equipment and its ability to efficiently do its job of transporting product from the place where it is expensively won to the market where its value can be realised.

Pipelines are a vital component in the oil and gas business model, the cost of whose even temporary loss will be counted in millions of dollars; the strength of whole economies hangs on their efficient operation and they sit for years or decades in a hostile environment carrying corrosive products. Protecting pipes and pipelines is a very important contributor to oil and gas efficiency, effectiveness and profitability.

John Hancock
Editor

John Hancock *joined as Editor of Offshore Technology Reports in early 2012. A journalist for nearly 25 years, John has written and edited articles and papers on a range of engineering, support services and technology topics as well as for key events in the sector. Subjects have included aero-engineering, testing, aviation IT, materials engineering, weapons research, supply chain, logistics and naval engineering.*

MesoCoat Develops Seamless, Corrosion-Resistant Clad Pipes for Deepwater and Onshore Oil and Gas Applications

MesoCoat, Inc.

Introduction

MesoCoat Inc., a subsidiary of Abakan Inc. (OTCQB: ABKI) has developed a new process for producing seamless, metallurgically-bonded, corrosion-resistant clad pipes This new fusion cladding process can produce clad pipe and plate approximately 40X faster than competing weld overlay or laser clad technologies and at significantly lower capital costs than conventional roll-cladding and mandrel expansion lining processes. The company's CermaClad™ high-speed fusion cladding technology, utilizes a focused arc lamp, "mini-sun" (300 – 500 kW delivered power) to rapidly fuse corrosion resistant alloys (CRA) and wear resistant alloys (WRA) to the inside of pre-fabricated pipes, plates, and large components such as T's and valves.

MesoCoat has recently completed construction of the world's first seamless, metallurgically-bonded clad pipe manufacturing facility at its Ohio, USA R&D and manufacturing complex. This facility brings to market a new option for seamless clad pipe, utilizing the company's CermaClad™ high-speed large-area fusion cladding technology that applies corrosion and wear-resistant metal alloys as a surface coating, followed by rapid-fusion (melting) using a proprietary high energy density, megawatt-class light source (arc lamp). This new facility will result in the commercial availability of seamless Alloy 625, 316L, and Alloy 825 clad pipes, with a true metallurgical bond available in pipe diameters from 10" to 36" and above. MesoCoat has completed construction and equipment installation at this facility which is expected to be fully operational by the end of April, 2013. It is important to note that no other facility worldwide can produce large diameter, heavy-wall, seamless, metallurgically bonded clad pipe. Abakan's CermaClad clad pipe manufacturing technology was recently ranked as the #1 Global Manufacturing Innovation by the Prestigious Wall Street Journal, was recognized by the Pipeline Industries Guild with the Subsea Pipeline Technology of the Year award, has received several R&D100 Industrial Technology awards, and has been recognized by Forbes magazine as Americas Most Promising Materials Science company.

MesoCoat has now secured land for a 4-line clad pipe manufacturing facility in Brazil and would begin construction of its Latin American facility this spring; this facility would have the capability to produce up to 100 kilometers of 10" CRA clad pipes and is anticipated to be operational in

FIGURE 1: CERMACLAD ARC LAMP'S 40 TIMES WIDER APPLICATION AREA COMPARED TO WELD OVERLAY COUPLED WITH RAPID FUSION, LOW HEAT AFFECTED ZONE, MINIMAL DILUTION AND POROSITY ENABLES MESOCOAT TO PRODUCE CLAD PIPES AT RATES UP TO 100 TIMES FASTER THAN WELD OVERLAY.

It is important to note that no other facility worldwide can produce large diameter, heavy-wall, seamless, metallurgically bonded clad pipe

FIGURE 2: CERMACLAD HIGH INTENSITY ARC LAMP CLADDING THE INSIDE DIAMETER OF PIPE WITH 3 MM THICK ALLOY 625.

early 2014. MesoCoat has also made progress towards an 8-line clad pipe manufacturing facility to be constructed in Southeast Asia by mid-2014 to clad large diameter pipes with stainless steel and other corrosion resistant materials primarily for the corrosive gas reserves in the Asia-Pacific region, that is experiencing a growing demand for corrosion-resistant clad pipes. Due to low capital and fixed operating costs, MesoCoat's global expansion plans include adding clad pipe facilities and local content in Brazil, USA, Indonesia, Middle East, and Canada over the next 2-5 years. All these planned facilities would have 4 to 8-lines of manufacturing and each of these facilities would have flexible capability to produce nominally 85 kms of 16" clad pipe or equivalent. MesoCoat intends to be able to meet a significant portion of the anticipated future demands for local content and increased clad pipe capacity in the up and coming energy producing regions by 2015.

Clad Pipes Overview

Cladding refers to a process where a metal, corrosion resistant alloy or composite (the cladding material) is bonded electrically, mechanically or through some other high pressure and temperature process onto another dissimilar metal (the substrate) to enhance its durability, strength, or appearance. The majority of clad pipes made today use carbon steel as the substrate and nickel, nickel alloys, and stainless steel as the clad materials to be bonded. Typically, the purpose of the clad is to protect the underlying steel substrate from the environment it resides in.

The International Energy Agency estimates that more than 70% of the remaining oil and gas reserves are highly corrosive and an increasing share of global oil and gas production is now offshore. Improving technology is allowing economic production from such corrosive and deepwater reserves. Development of such reserves substantiates the need for pipes and components that have high reliability and low maintenance costs. A key approach to this is the use of corrosion resistant materials that de-risk the production from such corrosive reserves by a great extent. Corrosion Resistant Alloy (CRA) tubulars provide the corrosion resistance needed when gas drilling and completion operations involve severe downhole conditions where CO_2 and H_2S are present. The eventual choice between use of either solid corrosion resistant alloy pipe or a carbon steel pipe clad with corrosion resistant alloy is made considering primarily the cost-to-benefit and weight implications. For technical, economic, and supply reasons; generally the pipes are not made entirely of stainless steel or nickel alloys. Clad pipes have multiple applications in the upstream oil and gas industry such as steel risers, subsea flowlines, wet gas pipelines, jumpers, and spools.

Clad pipes are used for onshore and offshore pipelines that need to achieve a balance between the mechanical properties of the carbon steel pipe and the corrosion resistance properties of a Corrosion Resistant Alloy (CRA). Oil and Gas production fluids often contain a high sulfur or CO_2 content that requires the use of materials suitable for corrosive environments. When the H_2S and CO_2 content are too high for the corrosion resistance properties of carbon steel, a CRA is often employed. Both clad and lined pipes consist of a carbon steel pipe which has a layer of CRA in contact with the corrosive production fluids. Clad pipes can be produced by many methods including forming pipes from large plates that are clad using explosion, roll bonding, and diffusion bonding, mechanical bonding, weld overlay, laser cladding, and co-axial extrusion. In the case of clad pipes, the layer of CRA is applied using different procedures that create a metallurgical bond, while the lined clad pipe is applied through a mechanical bond between the CRA and the carbon steel pipe. Clad pipes offer an optimum solution to the most demanding requirements of strength, corrosion resistance and cost-effectiveness. The outer carbon steel pipe handles the internal and external pressure, while the CRA cladding provides the corrosion protection. Current processes for producing clad steels suffer from limitations and drawbacks, including less than optimal bond strength, and dimensional and wall thickness limitations, or low productivity in the case of laser and weld overlay processes.

The global oil and gas capital expenditure (CapEx) is expected to increase from $1,036 billion in 2012 to $1,201 billion in 2013, registering a growth of 15.9%. The trend of increasing capital expenditure is expected to continue for the foreseeable future, especially driven by reserves that are deeper and farther away from the shore. Infield Systems Deepwater and Ultra-deepwater Market Report states that the largest proportion of deepwater investment is to be directed towards pipeline installations, comprising 39% of total global deepwater expenditure – and clad pipes would constitute a healthy share of this offshore pipeline investment.

CermaClad CRA Clad Pipe Overview

The CermaClad clad pipe manufacturing technology utilizes a high-intensity arc lamp (up to 1MW in power) to metallurgically clad corrosion and wear-resistant alloys to the internal and external surfaces of pipes that are primarily used for production and transportation of Oil and Gas. Compared to competing mechanical-lined (bi-metal) pipe and roll-clad and welded pipe, the CermaClad process produces a true, fused, metallurgical bond tested to over 70,000 psi tensile and 31,000 psig shear strength in a seamless (weld-free) 12 meter pipe product. Unlike weld overlay, the high productivity of the CermaClad fusion cladding technology is truly scalable (40X higher productivity than weld overlay), and does not produce overlay dilution, enabling improved corrosion resistance and thinner coatings to be produced to meet application requirements. Independent testing at the largest risk management laboratory, Det Norske Veritas (DNV) sponsored by MesoCoat's technology development partner, Petrobras S.A (NYSE: PBR), has confirmed that CermaClad product provides a better product with 95% lower dilution, 50% higher bond strength, and significantly higher mechanical integrity and toughness, compared to the defining API 5LD standard requirements for metallurgically bonded clad X65 pipe.

Exploration and Production of Corrosive Oil and Gas Reserves

- **Solid Alloy Pipe:** Solid alloy pipes are very expensive (8-20 times the cost of carbon steel pipe) and have limited availability and high installation costs due to welding difficulties.
- **Thicker Carbon Steel Pipe:** Lowest cost option but may require periodic replacement, and lead to several issues with reeling, laying and buoyancy due to the added thickness and weight of pipe. Also, project costs are increased

FIGURE 3: CERMACLAD CLAD PIPE PRODUCTION PROCESS FOR METALLURGICALLY CLADDING THE INSIDE AND/OR OUTSIDE DIAMETER OF PIPES WITH CORROSION- AND WEAR- RESISTANT ALLOYS IN THICKNESSES RANGING FROM 100 MICRONS TO 15+ MILLIMETERS.

CermaClad™ Sample	Mass before test, grams	Mass after test, grams	Mass loss, grams	CermaClad™ corrosion rate, mpy	Weld cladding corrosion rate, mpy	Rolled alloy 625 plate corrosion rate, mpy
1	27.6214	27.5587	0.0627	9.698	65	7.8
2	23.0743	23.0084	0.0659	10.193	65	7.8
3	22.7408	22.6666	0.0742	11.476	65	7.8

TABLE 1: ASTM G 28 TEST WITH CERMACLAD™ CRA SHOWED FIVE TIMES BETTER CORROSION RESISTANCE THAN WELD OVERLAY FROM DNV TEST SERIES 2011-N6.

The global oil and gas capital expenditure (CapEx) is expected to increase from $1,036 billion in 2012 to $1,201 billion in 2013, registering a growth of 15.9%

substantially due to need for additional lines for pigging and maintenance.

- **Mechanically Lined Pipe:** Lower in costs compared to metallurgically clad pipes but provides only marginal contact between the inner and outer pipe leading to higher possibility of buckling, wrinkling and disbonding under stress, bending, or during reeling. There is also a concern with respect to the uniformity and reliability - and air gap coupled with mixture of materials leads to challenges in NDT inspection which adds further risk towards the reliability of these pipes.
- **Weld Overlay or Laser Clad Pipe:** The production process is not efficient for general production and is generally suitable for urgent, low volume orders even though these pipes are generally more than 5 times the cost of carbon steel pipe and 30-40% more expensive compared to plate-to-pipe. The slow production processes cause long lead times for large orders, and high local heat input leads to significant dilution (back-mixing) of the substrate. Poor inspectability and inherent roughness of weld surfaces creates long term concerns.
- **Plate to Pipe (roll-clad):** Large pipes made from clad plates cannot be longitudinally welded and have to be welded spirally or in even smaller sections for pipe over about 24"diameter (failure of welds is a primary reason for oil and gas spills and leaks). Pipe to plate also is not an efficient method for making small diameter pipes from plates. The economics involved make it suitable only for making pipes at least 12" in OD from plates that are clad using roll or explosion bonding.

CermaClad Technical Specifications

The CermaClad™ High Density Infra-Red (HDIR) cladding process uses light emitted from a plasma arc lamp which is concentrated into a line focus at 500- 3500W/cm2 to rapidly heat the surface at up to 1,000,000 degrees per second in order to melt, fuse, and bond a layer of metal such as Inconel 625, Inconel 825, stainless steel, metallic glass, chrome carbide, or titanium to a structural backing metal such as X65 line pipe. The arc lamp consists of two electrodes separated by argon gas which, when charged, turns into plasma radiating in the optical and infrared spectrum and generating a radiant heat similar in intensity to conditions at the surface of the sun. To keep the lamp cool, jets of highly pressurized deionized water move around the tube's inner wall. A specially designed metallic reflector collects the radiant energy of the arc, focuses, and directs it to whatever material is below the lamp. Under a cooperative agreement with Petrobras, the lamp has been miniaturized and integrated into a robotic system for cladding inside a pipe. In the CermaClad™ fusion cladding process, a metal precursor powder is applied as a paint to the surface to be clad (such as seamless pipe), and then the surface is scanned with an arc lamp to fuse and metallurgically bond the cladding.

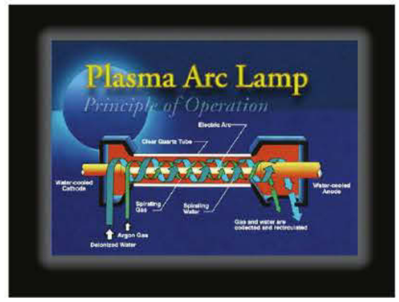

FIGURE 4: THE FIGURE REPRESENTS THE FUNDAMENTAL PRINCIPLE OF OPERATION OF THE CERMACLAD ARC LAMP (PICTURE: COURTESY VORTEK INDUSTRIES).

One of the advantages of the CermaClad™ fusion cladding process is that there is no electrode stirring, and only limited Marongoni convective mixing, leading to metallurgical bonding with low dilution of the cladding with the

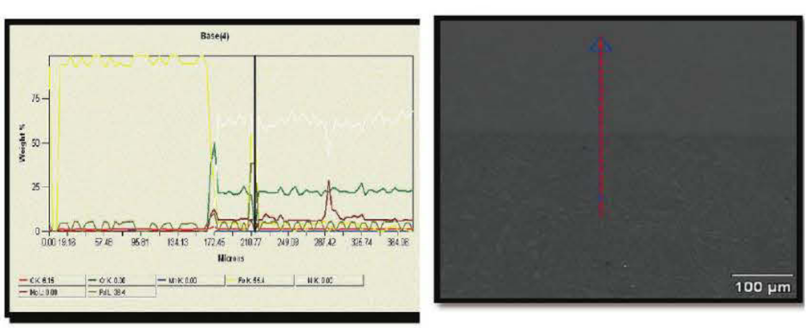

FIGURE 5: EDX LINE SCAN SHOWING FE, CR, NI, AND MO CONTENTS OF FUSED ALLOY 625 OVERLAY, AND LACK OF IRON DILUTION IN OVERLAY.

base metal. This can lead to improved corrosion resistance, as well as enabling the use of thinner coatings at a given iron dilution concentration. Figure 5 is an EDX line scan showing both a metallurgical bond (inter-diffusion zone), as well as the low cladding dilution.

Summary

The International Energy Agency estimates that over 70% of the world's remaining Oil and Gas reserves are extremely corrosive, and hence Oil and Gas production and transportation will require increasing quantities of corrosion resistant clad pipes. CermaClad high-speed large-area fusion cladding process has the potential of meeting future clad pipe demand and local content requirements, as the process is up to 40X faster than the conventional weld and laser metallurgical cladding processes, offers superior metallurgical properties with a seamless product and is highly cost competitive having low fixed, variable, and capital costs compared to alternate production methods. The speed of this process and resulting productivity of the equipment enables flexible supply, the lowest capital cost per unit production, and small process and labor footprint for reduced costs.

Compared to competing mechanical-lined (bi-metal) pipe and roll-clad and welded pipe, the CermaClad™ clad pipe provides a true metallurgical bond tested to over 70,000 psi tensile and 31,000 psi shear strength in a seamless (weld-free) 12 meter pipe product. Unlike weld overlay, the high productivity of the CermaClad™ fusion cladding technology is truly scalable (40-100X faster than weld overlay), with minimal dilution and porosity, enabling improved corrosion resistance and thinner coatings to meet application requirements. Independent testing conducted to industry standards has confirmed that CermaClad™ product complies with current industry standards, including API 5LD and DNV–OS-F101.

Developmental CermaClad™ products include CermaClad™-HT, high temperature cladding for energy production and heat exchangers, including titanium claddings. CermaClad™-LT low thickness cladding takes advantage of the low dilution of the process to apply a 3-10 mil corrosion-resistant cladding to protect from atmospheric and marine corrosion, while CermaClad™-WR wear resistant products include metal matrix composite, amorphous metal, and nanocrystalline carbide overlays to extend component and pipe life in critical high wear applications. MesoCoat is now commercializing several of its corrosion and wear-resistant products and has verified performance, productivity, and cost benefits with industry leaders.

CermaClad high-speed large-area fusion cladding process has the potential of meeting future clad pipe demand and local content requirements, as the process is up to 40X faster than the conventional weld and laser metallurgical cladding processes, offers superior metallurgical properties with a seamless product and is highly cost competitive having low fixed, variable, and capital costs compared to alternate production methods

A Key Component in a Vital Sector

Peter Dunwell, *Correspondent*

The importance of pipelines in the offshore oil and gas sector

When the price is right and can be realised, it will be worth undertaking extraordinary engineering and technology programmes in pursuit of a product. And so it is with deep sea exploration for and production of oil and gas

Demand Drives Development

As the world grows increasingly hungry for energy and with little prospect that any sustainable or renewable resources will be developed to fill that appetite in the near future, there is a burgeoning incentive to find further reserves of carbon based fuels. In reality, much of the world's carbon fuel reserves are already known but not all are yet exploited. There are several reasons for this but the most frequently cited is that as yet unexploited reserves tend to be in inaccessible or inhospitable environments… or both. There are few environments more inaccessible or hostile than the oceans but there are significant reserves of oil and gas to be found at ever increasing distances from land, far beneath sea-beds that are themselves deep below the ocean's surface. It's a significant challenge.

However, as we know, when the price is right and can be realised, it will be worth undertaking extraordinary engineering and technology programmes in pursuit of a product. And so it is with deep sea exploration for and production of oil and gas.

"Annual deepwater expenditure [was] predicted to reach around US $35 billion in 2014, with a total global [capital expenditure] of $167 billion estimated for the 2010-2014 period…" according to Thom Payne and Douglas-Westwood writing for E&P in 2010[1]. They went on to explain that, *"Three main elements dominate deepwater spend over the next five years: the drilling and completion of subsea development wells, pipelines, and production platforms. To put this in perspective, $63.6 billion will be spent on the drilling and completion of subsea wells alone... The opening up of reserves further from the coast and the incorporation of satellite fields into deepwater hubs will drive expenditure on pipeline and control lines to more than $62 billion."*

The Significance of Pipelines

This gives a clue about one of the most important elements in offshore and deepwater oil and gas. Pipelines have long been used to carry materials, *"but arguably the most valuable are those transporting crude petroleum and refined petroleum product including… oil [and] natural gas…"*[2] They also make a sensible alternative to loading product gained from undersea installations onto tankers for transport. *"Subsea pipelines can be a feasible and cost-*

saving alternative. Avoiding the construction of long stone jetties means less ocean bed is disturbed. Avoiding channel dredging also reduces the impacts to biologically sensitive areas and [means] less disruption to navigation during the construction and future maintenance dredging."[13]

Pipelines in the offshore oil and gas sector tend to fall into three main groups of field - infrastructure (gathering product from one or several wells to a central distribution point); global infrastructure (transporting product to market); and distributing product within the market – strictly speaking onshore, but still important for the offshore industry).

Whichever is the type of pipeline, it has been the development of large undersea oil and gas fields that has prompted technological advances in pipeline technology… *"in transportation or disposal techniques that range from improved pipe-loving techniques to the design of offshore loading systems."* is how OnePetro, 'The Economics of Disposal Methods for North Sea Oil and Gas Fields: A Study in Comparative Advantage'[14] puts it. The article first sets the scene by stating that: *"The development of gas fields and the production of associated gas from oil fields has been hampered by the lack of pipeline systems for disposal. With no fall-back position of offshore loading, gas fields cannot be developed unless there is an economic disposal method by pipeline."*

The Characteristics of Deepwater Pipelines

Pipelines are important to the offshore sector and so, the better they work, the more they contribute to a profitable business. That is probably why the 'Deepwater & Ultra-deepwater Pipelines Conferences'[15] include two days of presentations on just that topic. According to the Peritus OPT Series paper 'Inspection Maintenance and Repair of Deepwater Pipelines' (no longer available online) there are a number of characteristics that identify deepwater pipelines from their land or shallow water equivalents, including:

- Water depths are beyond diver limits;
- Wall thickness are typically high;
- All inspection, maintenance and repair is performed remotely;
- High levels of insulation are commonly required;
- Pipelines tend not to be protected by a concrete coating;
- Geohazards can be significant;
- Seabed mobility is less dominant;
- Corrosion coatings tend to be of very high quality.

Part of the Furniture

Pipelines serve several purposes in the offshore oil and gas sector. In some fields, pipes are used simply to move the product from the well to a local storage facility near the production point. From there, it can be loaded onto tanker vessels for transportation to shore-based refinery and distribution systems. However, on an increasing scale, pipelines and networks of pipelines are being used to fulfil the whole transportation function from well to shore. In this function, pipelines are growing in length as the technology to design, manufacture, lay and maintain them grows. The major offshore production areas, North Sea, Africa, Middle East, American waters and, increasingly, South East Asia, are all developing networks of undersea pipelines to move product around the fields, to consolidate transport to shared pipes and to help the environment by saving on the carbon cost of shipping.

They also save on labour costs and are generally more reliable than ships for delivery purposes. But undersea pipes are subject to considerable challenges even when they run in shallow waters. In deep and very deep waters most of those challenges increase significantly although one or two actually reduce.

What is in no doubt is that pipelines are an essential component in the offshore oil and gas business model and that, without them, getting the energy supplies we need to the places where we need them would simply not be possible.

An Economic Asset

John Hancock, *Editor*

The exploitation of most new reserves would not be possible without pipelines

As more oil and gas reservoirs are discovered in deep water, oil and gas exploration and development have been gradually moving farther offshore and into deeper and colder water with production wells in water exceeding depths of 10,000 feet

Pipelines; the Economic Case

Whatever else one might say about the offshore oil and gas sector, there is no doubt that it is subject to the scrutiny and requirement to return a profit that is a feature of all successful businesses. Therefore, no matter how wonderful the engineering and technology solutions used in the sector might be, they are also subject to the unforgiving laws of profitability. *"The challenges to subsea production in the future are considerable, with solutions required to the economical extraction of oil and gas from ever deeper waters in remote locations."* This quote is taken from the introduction to an Orcina course on 'Offshore Pipelines and Subsea Systems': Unfortunately, the course information is no longer available online. For our purposes in this article the keyword is 'economical' because with the deployment of pipelines, as with any component in the oil and gas offshore infrastructure, the considerable financial outlay needs to be matched by an even more considerable financial return for the business case to be made.

As more oil and gas reservoirs are discovered in deep water, oil and gas exploration and development have been gradually moving farther offshore and into deeper and colder water with production wells in water exceeding depths of 10,000 feet. Necessary measures to maintain the pipeline and other equipment as well as any unsound conditions or potential problem areas are considered. After oil and gas fields are discovered the next challenge is to move the product to onshore refining or processing facilities[6]. And that is where pipelines play an increasingly critical role.

The Market for Offshore Oil and Gas Pipelines

The economics of pipeline developments are subject to the same global trends and developments as any other economics. As 'The Oil & Gas Pipelines Market Analysis 2010 – 2020' from Visiongain[7] explains:

"… global spending in 2010 on oil and gas pipelines [was projected to] total $55.1bn... The oil and gas pipelines market is being influenced by two factors. The requirements for new pipelines to cope with the supply demands in the pre-recession global economy were clearly seen. However since the global downturn in industry and manufacturing, there is now sufficient pipeline capacity again to service the current consumption and the present economic climate is restricting spending on new oil and gas pipelines around the world, but particularly in the US and the UK.

"As the economy picks up again, the demand will start to out-pace supply, leading to high market pricing and increased costs of materials from manufacturing, meaning that the cost of new pipeline projects will also rise. The main challenge for the oil and gas pipelines industry therefore remains the uncertainty of the market and how to maximise value for money in the construction and operation of new and existing pipelines."

The Challenges of Offshore Pipelines

Visiongain's report, of course, referred to all pipeline developments but would be particularly apposite for offshore developments in which not only are the normal economics of pipeline development magnified but also a number of additional and costly environmental challenges have to be faced in both directions: the impact of the underwater environment on the pipe and the potential for 'difficult to manage' pollution in the event of failure. "PetroMin Pipeliner" magazine included an excellent summation of the challenges specific to the extremes of offshore pipeline developments in its April-June 2012 edition article 'Deepwater Pipeline Management – Problems and Solutions'[8].

The key growth market in the already challenging offshore oil and gas sector are the deepwater and ultra-deepwater opportunities being driven by the market's need for more energy at almost any cost. Infield Systems' 2012 edition of the 'Deepwater and Ultra-deepwater Market Report to 2016'[9] is very positive; "As the key growth market within the offshore oil and gas sector and the most capital intensive area for development, the emerging trends within the deep and ultra-deepwater sector reflect the dynamic state of the industry and the level of operator optimism going forwards." The report also states that, "the largest proportion of deepwater investment [of 1000 $201 billion in 2013, is] to be directed towards pipeline installations; comprising 39% of total global deepwater expenditure."

Not Only the Building of New Pipelines

The technical and economic challenges that accompany offshore pipelines are far from over when the pipeline has been laid and installed. As oil and gas fields mature, and as ways are found to exploit what were once considered more difficult reserves, the life of fields is extended, which is good, but also the working life of infrastructure including pipelines has to be extended in order to maintain the economic case for more difficult reserves. For instance, "Many offshore pipelines in the North Sea are over 30 years old and may be required to operate well into the 21st century as the North Sea continues to supply oil and gas. It is essential that the pipeline infrastructure is maintained in order to meet these future energy demands." These were the words used to introduce the Institution of Mechanical Engineers' course 'Offshore Pipelines: Life Management & Fitness for Service'[10].

As the lives of fields are extended, we must pay heed to this longer term view of pipelines and the engineering needed to ensure that pipelines currently in place can be operated, perhaps, beyond their planned life. Also, that new pipelines should include materials to ensure a longer life than their immediate purpose might suggest.

The Wider View

While it may well be the case that companies in the oil and gas sector have to operate commercially and make a profit in the same way that all companies do, for national governments looking at the sector it may be that there are wider

economic benefits that make the investment, including the significant investment in pipeline technology, worthwhile for them. These wider benefits need to be considered and the cost of both building and maintaining a subsea pipeline needs to be viewed in this wider context.

The discovery and exploitation of oil and gas reserves can transform a national economy. Not only is the product itself very valuable but also it can drive improvements in employment and technical skills in the locality of the reserves. That will, in turn, benefit the economic capability of the country and generate tax revenues which will significantly affect the ability of a government to provide for its people those staples of modern life such as good communications, healthcare and education.

This may seem a long way from pipeline technology, but the reality is that significant developments in the ability of pipelines to remain and to function in deep sea conditions are a keystone in the ability of nations to exploit the mineral resources beneath their oceans. The economic case for pipeline technology and the development of pipes that can function at depths and whose durability will enable them to continue to function for a long time, is at the heart of the economic case for offshore oil and gas exploitation.

A Hostile Environment

Francis Slade, *Staff Writer*

No two ways about it, deep sea operations are hazardous.

The International Energy Agency has estimated that more than 70% of remaining oil and gas reserves are of the highly corrosive type

Deeper Water: Greater Challenges

In a May 2013 interview with O&G Next Generation[11], Dr Neil Thompson, Ex-President of the National Association of Corrosion Engineers (NACE) said; "Most often hostile environments are associated with offshore pipelines and facilities. As production goes deeper, the environments of production almost always become more hostile (temperature and pressure) and often with higher concentrations of aggressive species (e.g. H 2S, CO 2, solids, water). Selection of materials that will provide the intended performance becomes more critical because replacement due to corrosion, cracking, and erosion is extreme costly. Therefore, the design phase is critical and corrosion control often is a question of material compatibility with the environment." His use of words like 'hostile' and 'aggressive' suggest, correctly that the challenges facing deep sea pipelines are as threatening as they are intellectual.

Undersea pipelines used in offshore oil and gas collection and transportation are themselves complex engineering structures that need to meet multiple demands. It isn't only the mechanical factors mentioned by Dr Thompson but also concerns such as thermo hydraulic performance. This is a subject that would warrant a paper in its own right but relates to the need, particularly in the case of oil drawn from deep below the surface of the Earth where it may be warm and able to flow relatively easily, to be transported through a deep water pipe in very low temperatures that could affect the ability of the product to flow. Therefore materials that can aid both installation against external cold and reduce resistance within the pipeline will be very important for the efficient operation of that pipeline.

Corrosion

Before going into any technical details, pipelines in deep seawater are set in an inherently hostile environment. Having already mentioned corrosion in his list of threats, Dr Thompson went on to estimate that it costs gas and liquid transmission and gas distribution pipeline operators up to $12 billion every year. Now, while that figure will include onshore and offshore installations, there is no doubt that the corrosion threat faced by offshore infrastructure will be considerably more than that faced by onshore facilities. There are several factors that govern how corrosion mechanisms work in a deep water environment.

In his 2001 Technical Paper, 'External Corrosion Control and Inspection of Deep Water Pipelines'[12], Jim Britton explains how the deepwater environment differs from shallow water areas and how those differences affect not only the prevalence of corrosion but also the external factors that could inhibit corrosion. *"The external corrosion control of offshore pipelines has… been accomplished with pipe coatings supplemented with galvanic cathodic protection in the form of zinc or aluminum anode bracelets."*

Cathodic protection relies on a small electrical current to inhibit corrosion. Unfortunately, as Jim Britton says, *"The electrical conductivity of seawater increases as temperature increases, thus at depth [where temperatures are lower] the conductivity is lower. This means that the amount of cathodic protection current which could be expected from a conventional anode will be much lower in deep water than in shallow water."* Continuing to review corrosion defence methods, he adds, "… *coatings are the primary external corrosion defense."*

Also, as increasingly difficult or economically more challenging reserves are exploited, that almost inevitably means lower quality crude products and the International Energy Agency has estimated that more than 70% of remaining oil and gas reserves are of the highly corrosive type. This will pose particular challenges in protecting pipelines not only from the corrosive degradation caused by the external environment, but also from the corrosive effect of the product they carry. Plus, in a colder environment, a build-up of the paraffin wax contained to a greater or lesser degree in all crude oil, might cause a build up inside the pipe that, again, will inhibit flow.

This can be cleaned off using pipeline inspection gauges (PIGs) but it all adds to expense and reduces efficiency.

This can cause problems from the actual loss of pipe strength and integrity (a problem in deep water, high pressure environment) to the loss of a smooth internal surface which will, in turn, inhibit the efficiency with which the product flows, and the rate at which it can be extracted and its value realised.

Other Threats

But corrosion is not the only threat faced by a deepwater pipeline. Wear and tear, while it sounds more mundane, can be every bit as threatening to a deepwater pipeline. And any threats to a pipe's integrity will have multiple consequences. Obviously, the financial cost of any loss of product through a leak, however caused, will be worrying in a field where costs are already so high. But it can get worse. Leaks can lead to pollution, a word that has most oil and gas professionals breaking into a cold sweat at its very mention. More prosaically, ideally a pipeline will last as long as the reserve it is used to exploit. However, as further exploitable reserves are identified within currently active fields, operators will wish, wherever possible, to extend the life of pipelines already in situ rather than incur the expense of building new infrastructure. It might even be the factor that determines the viability of extended operations.

Other factors against which pipes will need to be protected are the effects of movement over the seabed due to local currents and the possibility of collision with fishing trawls or even the risk of being struck by dropped objects, including anchors. And we cannot ignore the factors inherent in pipe construction methods, including the testing of welds in a high pressure environment.

All in all, an undersea pipeline leads a pretty demanding life for which any protection that can be afforded the materials or the finished item will add to its ability to do the job efficiently despite the threats.

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Protection from Harm

John Hancock, *Editor*

Taking the right steps will protect against the elements but also against the potential cost of failure.

Because steel is the most common component in pipelines, it can render them vulnerable to corrosion on the outer surface with immersion in salt water, and on inside surfaces from the corrosive nature of products carried

Prevention is Better Than Cure

Previous articles in this paper have examined why pipelines are important to offshore oil and gas, their economic significance and the very real threats to their continuing operability and profitability. In the light of all this (summed up as 'they're important and they're vulnerable') the final question has to be how can pipelines be protected against threats in order that they might continue to operate… and how can operators discover any damage or loss of integrity before it becomes a crisis?

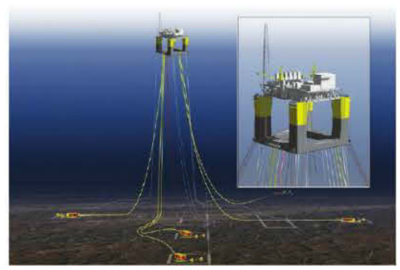
That can be very difficult operating at thousands of feet below the surface.

One way in which operators do 'keep an eye' on their infrastructure, including pipelines, is to use an underwater ROV (remotely operated vehicle). ROVs are much more than submarine mounted cameras.

"Existing pipelines can be surveyed with ROV mounted survey systems - high and low resolution systems are available… High-resolution systems will give not only accurate potential profiles of the line but also current density, this is particularly important if a remaining life estimate is required."[13] It is also possible to build monitoring systems into pipelines to measure movement, stress and other external factors. However, as with much in life, in this area, prevention is better than cure. Once a pipe has been laid and incorporated into a system, there are limited options available for repair or replacement should it fail and all of those options are expensive on every level.

As Dr Neil Thompson, in O&G Next Generation[14] puts it; *"It is typically presumed that the largest savings can be achieved by implementing corrosion control practices at the design stage; this includes pipeline integrity management and risk assessment. It is much more cost effective to include 'asset risk management' practices, including best practice mitigation, at the start of the asset life cycle as opposed to waiting until failures lead to enhancement of practices requiring costly maintenance and repairs."*

In fact, this approach was enshrined in UK law in 'The Pipelines Safety Regulations 1996' Part IV.4[15] which states…



CLAD PIPE FOR SUBSEA APPLICATIONS.

Design of a pipeline

The operator shall ensure that no fluid is conveyed in a pipeline unless it has been so designed that, so far as is reasonably practicable, it can withstand –

a) Forces arising from its operation;
b) The fluids that may be conveyed in it; and
c) The external forces and the chemical processes to which it may be subjected.

Protective Coat

Because steel is the most common component in pipelines, it can render them vulnerable to corrosion on the outer surface with immersion in salt water, and on inside surfaces from the corrosive nature of products carried. External corrosion can lead to leaks or worse which, in turn, can affect production or cause environmental damage and the ensuing reputational harm. Internal corrosion roughens the surfaces in contact with the product which will manifest as reduced flow efficiency. One of the best solutions for this problem is to use a coating material applied at the manufacturing stage which will enhance flow, improve flow efficiency, offer corrosion protection in storage, reduce pumping costs, improve commissioning, provide a sealed surface and ensure product purity[16].

New processes mean that pipes can be clad and/or coated with corrosion resistant materials at the point of manufacture which, in the case of steel pipes, means that they are protected even during the journey to site – that can, itself, be quite a challenge in deep sea operations. Usually a corrosion resistant alloy or composite is bonded to the pipe.

Extended Operational Life

Those benefits from protecting a pipeline against its most insidious threat, corrosion, might be regarded as short term, inasmuch as the impacts of failures are on day to day operations. But, to an increasing degree, operators are seeking to extend the lives of installed pipelines for a number of reasons which really boil down to one; more production. Whether a new field has been located adjacent to one currently operating or improving technology and engineering plus better market economics (higher price) make once unviable reserves now viable, in mature fields much of 'newly discovered' reserves are actually right where old reserves have been exploited for years or decades. So it makes financial sense to use the infrastructure already in place. But that will only be possible if the components are still in safe and serviceable condition. A pipeline that was built from resistant parts at the outset and that has been well maintained is more likely to meet those criteria.

But extended lifespan pipelines do pose some particular maintenance challenges. As DNV puts it in the paper 'Safely extending the lifespan'[17], "As pipelines are put into operation or approach maturity in their design life, a different set of considerations and capabilities are required in order to manage the integrity of the pipeline system."

Also, if a pipe does fail through any problem – corrosion, reservoir pressure, damage to the pipeline, etc., – in UK waters, "the Secretary of State has the option of immediately calling for a full decommissioning programme."[18] Of course, it might be that the operator will be happy to decommission in order to get on with new projects but, equally, they might wish to wait for a more convenient time, such as the end of the field's life. The Secretary of State has that discretion, but much will ride on pipe safety, so good build quality and maintenance can also pay dividends here.

Safety First

The over-riding consideration in everything that a pipeline operator does will be safety. As UK Health & Safety Executive (HSE)[19] says, "We believe that where pipelines are properly designed, built, operated, maintained and eventually decommissioned they are safe for the pipeline workforce and the general public."

That seems like a very sound sentiment on which to close.

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