Technology Status Assessment

Development of Carbon Nanotube Composite Cables for Ultra-Deepwater Oil and Gas Fields

RPSEA Subcontract 09121-3300-10

Document Number: 09121-3300-10 – Technology Status Assessment – 07-13-11

Task 2.0 Deliverable: Technology Transfer Plan

The purpose of this project is to develop a new technology for building electrical power cables that are a composite of carbon nanotubes (CNT) and copper. The goal of the project is to build a CNT-copper composite cable with double the conductivity of an equivalent size pure copper cable. Additionally, the CNT-copper composite cable should be lighter and stronger than a comparable copper cable. This new power cable will be able to carry more electrical power downhole into wells to power additional boost (pump) capability with a smaller diameter conductor. With its greater power handling capacity, the new composite cable may allow more processing components to be moved to the seafloor from surface facilities. The new cable technology could enable extending subsea tiebacks to longer distances through increased power carrying capability over longer distances. By increasing the capacity of carrying power without correspondingly increasing the size and weight of electrical cables, the new cable technology could help lower the cost of developing deepwater oil/gas resources.

Proposed Technology/Methodology

Carbon nanotubes (CNTs) are tiny cylindrically shaped objects, with diameters around 10 nanometers and lengths up to a few millimeters, and are made of pure carbon. Among their interesting features is extremely high electrical conductivity (more than 1,000 times as conductive as copper), high strength (more than 5 times that of steel) and low weight (density less than half that of aluminum). If the extremely high conductivity of individual CNTs can be harnessed to make higher conductivity electrical power cables, they could revolutionize the design of facilities that require large amounts of electrical power. A key application for a CNT-based electrical cable would be to supply power to downhole pumps in oil/gas producing wells. With severe space constraints, particularly within tubing hangers, getting the electrical power downhole for increasing amounts of downhole boosting is an increasingly difficult and expensive problem.

Building a power cable from a CNT-composite has not been feasible to date. Since individual CNTs are so small, building a cable to carry significant amounts of power will require many billions of them, and individual CNTs must be well connected electrically to many neighboring CNTs. In addition, the CNTs must be mechanically interconnected for the resulting cable to have mechanical strength and integrity.

We propose a bulk-based approach for achieving the high conductivity needed. Recent work at LANL has shown on test samples that it is possible to achieve or exceed a conductivity increase of 25% in a composite of CNTs and copper. The present project is high risk R&D, with potential for high payoff.

New domestic oil and gas production (especially oil) increasingly is from resources that are located in increasingly deep water (7,000 feet or more) and at increasing depths below the sea floor (30,000 feet or more). An individual well may cost several hundred million dollars to drill and complete. Efficiently producing oil from these deep wells requires downhole boost (downhole pumps) to bring it up from the deep reservoirs. Pump capacity of 1,000 hp or more may be needed to achieve sufficient production from an individual well. Moreover, downhole processing such as oil-water separation, is increasingly important for efficiently producing these deep wells. Both pumping and downhole processing require a substantial amount of electrical power down within a well. Currently, this power has been provided with thick copper cables that are run through the tubing hanger of the well and then extend thousands of feet down into the well. The cables occupy a substantial portion of the volume of the tubing within the well. If fewer or smaller cables could be used to get electrical power downhole, a well may be able to produce oil more efficiently, perhaps with a larger production tubing. Alternatively, more space may be available for additional equipment to do fluids processing downhole.

To power the production from deepwater wells electrical power must be carried from surface generation facilities to the sea floor and fed into the well. With development of fields in water depths of 7,000 feet and more, power cables may weigh many tons, and without support, they may break under their own weight.

Background and Existing Technologies/Methodologies

Power cables typically are copper, which is the most conductive of the plentiful metals (silver is about 5% more conductive than copper, but costs about 90 times more). Advantages of using copper for power transmission are its high conductivity, durability, and availability. Disadvantages of using copper are its high weight (its density is about 9 gm/cm3, or 9 times that of water), low strength and limited conductivity. High strength copper alloys are available for specific applications, such as high field strength magnets, although the alloys are expensive, in limited supply, and carry less power than ordinary copper cables.

Long-distance high power electrical distribution lines are often made from aluminum. The primary advantage of aluminum in this application is its low unit weight (its density is about 1/3 that of copper). The lower weight allows for much longer cable spans between support towers than would be possible with copper. Nevertheless, the conductivity of aluminum is only about 2/3 that of copper, and thicker aluminum cables are needed to carry comparable power. With the severe limit of space in wells, aluminum power cables are not a viable substitute for copper.

Superconducting power cables can carry 10 to 100 times the power of comparable sized copper cables with zero resistive loss. While superconducting cables are more expensive than copper, their greater power capacity could justify their additional cost. The main disadvantage of superconducting cables is their need for cryogenic cooling to keep them at superconducting temperatures. Maintaining the cryogenic cooling at water depths of thousands of feet would be considerably more difficult and expensive than at the surface and not technologically feasible at this time.

The goal of this project is to develop a new technology for building electrical power cables that are much more conductive, lighter, and stronger than copper cables. Carbon Nanotubes have about a thousand times the conductivity of copper, yet the technology needed to exploits the CNT conductivity has not yet been developed. If this work is successful, the project will build a prototype Carbon Nanotube (CNT) copper composite cable that, compared to a comparable diameter copper cable, carries twice the electrical power, may weigh half as much, and may be much stronger.

The potential applications and benefits of the new technology are two-fold: First, using the new cable technology in wells would enable greater downhole pumping (boost) capacity, which should improve the efficiency and reliability of production from them. By enabling additional downhole processing, the new technology may produce additional improvements in the efficiency of production, reduce environmental impacts from the production, and reduce the costs for a well. These should allow smaller fields to become more economic.

Second, the new cable technology should allow for lighter, smaller electrical cables in the umbilicals between surface facilities and equipment on the sea floor. The new cable technology could also provide the extra power needed to install and operate additional processing equipment on the sea floor. This could allow reducing the footprint of surface facilities, and may increase operational efficiency by doing more processing near wells, and reducing the volume of liquids that are transported to other locations to be processed, some of which may need to be transported again to be disposed of.

Interactions between the technical staff of Chevron and Los Alamos will provide important reviews of technical progress and help with decisions about project priorities. Chevron will make important in-kind contributions to the project through these staff interactions.

Expected Impacts and Benefits

Chevron (and the industry) has recently made major discoveries in the ultra deepwater of the Gulf of Mexico. Developing these discoveries and getting the energy to market can cost billions of dollars, and will require adapting existing technologies and developing new technologies. New technologies that can lower the immense cost of these developments will be essential to assure that the new discoveries can be commercialized as quickly and efficiently as possible, and help increase the nation’s access to secure sources of oil/gas energy. One key technology for successfully and economically developing these fields is getting enough electrical power to where it is critically needed. One of these critical needs is for greater amounts of downhole pumping (boost) to bring produced oil up and out of the wells. With the available space in the tubing hangers and the rest of the well severely limited, new power cabling is needed to get more power into wells and down to the pumps. Increased power in wells can speed up the development of new fields and lower its incredibly high costs. Reducing the costs of ultra deepwater development should help make development of smaller fields economic.

Impact on Reserves and Production

Successful development of the new power cable technology proposed should help increase the productivity of wells, and reduce the cost of completions. These should also help make smaller fields economic to develop and produce. The proposed new CNT-copper composite cable could be used to provide greater power at the seafloor to carry out more seafloor processing of produced liquids and minimize the need to transport undesired liquids for remote processing. The additional power transmission capability of the new cables may allow for power transmission to longer tie-back distances, and may reduce the number of surface generating facilities needed to produce from fields.

Successful development of CNT-copper composite cables with double the conductivity of pure copper cables should allow increased production from fields through increased downhole boost capacity. The new cables could facilitate installation of redundancy in the boost capability of boreholes, and thus, increase the reliability of operations and decrease the need for expensive workovers to replace failed downhole pumps. Availability of more power within wells should also encourage putting more liquids processing equipment down in the well, closer to where the production is, and could allow separation and reinjection of undesired liquids without the expense of pumping them up to the sea floor for processing.

Environmental Impact

Successful development of the new cable technology should allow for reduced environmental impact in development of new fields. If the power cable technology allows for undesired produced liquids to be separated downhole and reinjected, that could represent a significant benefit in reducing environmental impacts of field development. The new cable technology would carry power with lower losses than pure copper cables, which may allow use of smaller power generation facilities, with consequent lower costs and less fuel used to produce the power needed. Finally, the lighter cabling would have additional positive benefits for reducing environmental impacts associated with field development, although these would likely be relatively small.

Another potential impact of the technology is the introduction of possible safety hazards associated with handling of the carbon nanotubes. Although definitive studies have not yet been completed on the safety or dangers of carbon nanotubes, they are thought to represent a health danger if they are inhaled or ingested. As a result, they require special care to handle them safely, and this will impose additional safety burdens on a commercial cable fabrication facility. Once embedded within the CNT-copper composite cable, however, the carbon nanotubes should be fully contained and no longer a potential hazard. A CNT-copper composite cable should be able to be handled without any additional safety requirements compared to pure copper cables.

The new CNT-copper composite cable technology may require new fabrication facilities to produce it in commercial quantities. Nevertheless, once the CNT-copper composite cable has been fabricated, it should be able to be handled in the same way as pure copper cables are, and assembled into cable assemblies and umbilicals in the same way as pure copper cables are now. While Chevron will share the cost of developing the new CNT-copper composite cable technology, they do not plan to manufacture cable themselves. Instead, service companies, such as the manufacturers of the downhole assemblies, the tubing hangers, and the downhole pumps, could incorporate the new cable technology into their products, much as they do now with pure copper cables. If possible, an existing cable fabrication facility would be able to build the new composite cables. Since the potential market for this new type of cables extends beyond the oil industry, it should not be difficult to find a suitable vendor interested in building them. Nevertheless, this is an important part of commercializing the technology and will require careful attention especially during the last two years of the project, to assure that a suitable facility will be available as soon as possible after the technology is demonstrated. We expect this to be a critical part of the technology transfer activities of the project.

This project represents high-risk R&D. There is no assurance that the project will succeed in finding a way to build a CNT-copper composite cable that meets the stated goals. Success in developing the new technology will require major advances in materials and fabrication. Even if the project succeeds, building electrical cables is not a primary product of the oil/gas industry.

Although the product itself may be a key to development of new deepwater fields, that potential payback is not enough for a single company to invest the R&D that is needed to develop the technology. Thus, there is little willingness to fund this work. Further, the field of CNT is moving too fast to build a consortium of multiple companies to collectively fund the R&D to develop the technology. Chevron is not willing to commit to spending $2.5M to develop this new technology. It seems unlikely that any other individual company is, either.

Risks

The biggest risk for this project is that of technical failure: The planned technical approach is unsuccessful in developing a CNT-copper composite cable with the characteristics desired. The recent successful development at LANL of high conductivity cnt/metal composites mitigates the risk. But these are small samples. However even a partial success in meeting the stated goals of the project could be a significant benefit for developing ultra deepwater fields.

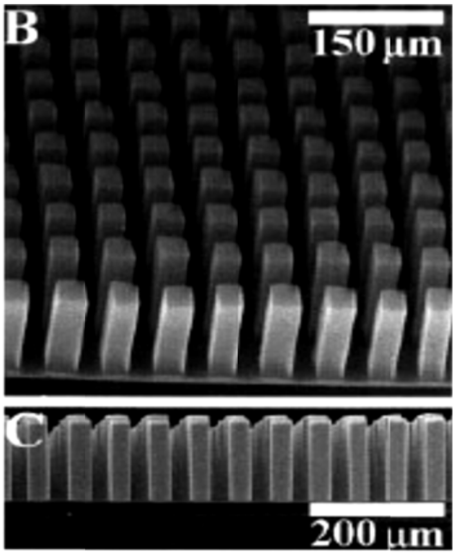

Figure 1. CNT Catalytic Growth by designing the catalysts appropriately, carbon nanotubes may be grown forming periodic square structures or “forests.” Recent developments at LANL have focused on making the “tree” height of the CNT “forests” into world leading 4.7-mm heights. Each square “tree” is formed from 370 million CNTs, all oriented and pointing in the high-conductivity vertical direction. These oriented structures can be embedded into a copper matrix to form practical composite conductors. Each “tree” in the figure is about the size of a human hair. The aspect ratio of the length divided by the diameter of each CNT is very high, about 0.47 $10^{\wedge 6}$.

Technical Background

The discovery of carbon nanotubes (CNT) by Iijima in 1991 is one of those rare technical breakthroughs which occur only a few times in a century. Based entirely on the element carbon, the nanotubes have shown outstanding properties: tensile strength greater than a TeraPascal (about 10 times the strength of steel.); electrical conductivity about 1200 times that of the excellent metal copper, and a composite density less than ½ that of aluminum .

The nanotubes themselves are about 10 nm in diameter and are available in a variety of lengths, depending on the growth technique. For a general review please see “Carbon Nanotubes” by S. Reich et al. (Wiley-VCH, Berlin, 2009)

In order the make practical use of the nanotubes, one must develop technologies which can deal with or manipulate the CNTs in great quantities. For RPSea applications one will need to make dense structures of the CNTs where they are aligned simultaneously along the direction of current flow, but also one will need to have methodologies so that one can electrically connect the tubes together in their transverse direction. This is a means to make high percolation conductivity though the entire CNT/Metal matrix ensemble.

Fortunately we at LANL have available two recent technologies developed which allow us to manipulate multiple CNT. The first has been developed by Greg Goddard of Bioscience Division. He has called his technique “Acoustic Flow Cytometry”. This technology manipulates small structures by using the pressure of acoustic waves of various polarizations. The second technology is called “Acoustically Engineered Materials” developed by Dipen Sinha of MPA Division. A focus of his work has been engineering of exotic materials through the use of ultra sound. The first of these techniques has been used to organize and align DNA molecules; the second has been used to align carbon fibers.

So the development of a practical CNT/metal matrix would consist of the following tasks or steps:

a) One secures a commercially available hollow copper “hypodermic” tube.

b) A slurry can be formed from commercially available CNT in an electrolyte. (These are presently being used to make CNT-based Ultra-Capacitors.

c) CNT are introduced into the inside of the tube a) using acoustic manipulation

d) The CNT highly align in the flow pattern.

e) They can be trapped to remain inside the tube by using a piezo radial end force.

f) The outer wall of the copper tube will have an insulating layer on it. With an electrical contact to the tube, copper ions can be deposited by having a copper plating solution flowing through the deposited CNT.

g) Because of the high density of the CNT, one can fill up the residual voids with plated copper.

h) As the plating is carried out, it is focused at the inner copper tube wall, growing toward the center. Additional different metallic ions in small quantity can be introduced to allow Redox percolation conductivity to be developed. This entire process makes a filled tube of high density and high electrical conductivity.

i) The pristine connectivity will be improved by drawing down the filled tube.

j) Heat treatments will also improve the percolation conductivity. LANL has both electroplating and wire drawing capability within its Sigma Complex. These processed wires can be wound together to make practical under sea cables, able to carry the needed power. It is envisaged that the process of producing the CNT/metal composite wires can be automated.

We believe we should contact under sea cable makers after the first year to ensure that the properties of our material are consistent with their needs. These include, but are not limited to

a) Ruggedness
b) Vibration proof
c) Chemical stability
d) Ability to withstand power surges.