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“Drilling, Completion and Stimulation Program”

Area of Interest 1: Deep Trek

Contract Number: DE-PS26-05NT42395-1

“Development of a High-Pressure/High-Temperature Downhole Turbine Generator”

Technology Status Assessment

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An increasing percentage of production, particularly natural gas production, will come from deeper and hotter wells than have been exploited to date. Estimates are that the producible gas in deep, hot formations is greater than 150 tcf. A fair percentage of the wells required to produce that deep, hot gas will encounter borehole temperatures in the 437°F to 482°F (225°C to 250°C) range. Producers and contractors have recognized this, and have for some time been making preparations to accommodate drilling and producing these reservoirs. Technologies that can be developed, or adapted, and applied to "intelligent" bottom hole assemblies (BHA's), such as logging-while-drilling (LWD) or measurement-while-drilling (MWD) tools, to allow operation of these systems in the extreme temperature environments expected, are being sought out, studied and applied.

The area of downhole electronics has long been recognized as the primary limiting component in high temperature applications. Most downhole electronics are rated for operation between 300°F to 345°F (150°C to 175°C). It follows, then, that the primary focus of the drilling industry has been to work with independent firms, joint industry projects and with the aid of United States Department of Energy research grants to develop electronics capable of meeting the higher temperature requirements mandated by the deeper, hotter drilling environments. Significant developments have been made in the area of Silicon-on-

Insulator (SOI) components that are now capable of withstanding operating temperatures above 392°F (200°C). Capacitor technology seems to be making significant high temperature headway as well.

The question remains, though, is there a reliable and available downhole power source to supply power to these next generation downhole electronics? Even the "smartest" BHA without sufficient and reliable power to run it does not help the drilling contractor. Downhole battery manufacturers have been working on solutions for the higher temperature issue as well. High temperature Lithium-ion batteries are commercially available with operating temperatures as high as 392°F, but there is a minimum operating temperature associated with these devices. As a result, a high temperature Lithium-ion battery pack that may operate at temperatures as high as 392°F may not function at all below 158°F (70°C). The batteries' capacities can also vary dramatically with the temperature at which they are being used. For example, a 392°F rated Lithium-ion battery will only have approximately half the capacity at 212°F (100°C) as it does at 392°F. Therefore, not only does the high temperature battery cost more to purchase due to its high temperature chemistry, it will last only half as long when used at a borehole temperature of 212°F. There is also a maximum amperage rate at which 100% capacity of the battery can be utilized. These issues pose real problems for deep, hot wells, as there may be a temperature variation as high as 482°F between the surface and total depth.

Frequent battery replacement is also problematic because the pressure seals protecting high performance electronic tools are not designed to be made-up and broken-out routinely. Just replacing a spent battery might require a complete seal replacement—a very costly and time-consuming task.

Because of these reasons, using the same battery pack to drill from conventional temperatures into hot temperatures approaching or exceeding 392°F would drastically reduce the effectiveness and life of the batteries and in turn radically increase the cost per ampere-hour. The alternative would be either tripping out and changing battery packs, which is unrealistic, or running redundant batteries and switching them at high temperatures. Neither option is attractive from a cost or logistics view.

It should be noted that there is significant work, funded by the US Department of Energy, Sandia National Laboratories and General Atomics, in the area of high temperature battery research. Prototypes have been produced very recently that show promise at temperatures up to 482°F. These same prototypes have also been shown to work at temperatures as low as 77°F (25°C) with limited current loads. These devices are based on high temperature fluoride battery chemistries developed by Dr. Alexander Potanin from VNIIEF in Sarov, Russia. General Atomic Company acquired the international distribution rights to this technology, and with the collaboration of Dr. Potanin they have continued the research. These devices are still some time away from being considered commercially available, as is their projected cost. Characterization of the power density potential for these devices is premature, as they are still in the developmental stages. Another important note is that the high temperature battery prototypes being tested are not Lithium-ion cells and do not carry any of the environmental, explosive or outgassing concerns associated with Lithium-ion cells.

Downhole mud driven turbine generator power appears to be a viable power option, particularly for the high temperature market. Downhole generators do not suffer many of the limitations associated with downhole batteries, such as narrow operating temperature ranges or power density variation across an operating temperature range. And while downhole batteries have an inherent dislike for instantaneous high current loads, downhole generators have proven to be able to accept high load requirements instantly and for a long duration.

Dexter has a line of downhole turbine generators rated for operation at 300°F, called UnderCurrent, which is being used for the basis of the high temperature design for this project. The UnderCurrent design eliminates all dynamic seals, ensuring there is no opportunity for the tool to flood through the failure of a rotary seal. The mud driven turbine blades are attached to a Dexter magnetic coupling, which in turn transfers the rotating energy from the turbines to the power generation module on the inside of an insulated pressure housing.

The UnderCurrent platform offers some advantages in the quest for achieving a reliable high temperature downhole power source that will provide high-density power across the broad temperature range that is encountered in deep, hot wells. The 3-phase power generation module used in the standard UnderCurrent tools is already rated to operate at 437°F. It is yet to be determined what mechanical design modifications to the tool housings that house the power generation module, to allow the entire system to operate reliably at these elevated temperatures. In addition to the required housing design review, another limiting factor thus far has been the temperature rating of the electronic components necessary for rectification and regulation of the output voltage. With the availability of some of the high temperature board level components mentioned earlier, Dexter anticipates being able to substantially increase the temperature rating on the power conditioning circuit. It is still to be determined what the upper temperature limitation for these components will be.

Static o-ring seals and electrical connectors suitable for application in the HPHT environment are additional areas that will need to be investigated. There are no standard connectors available with the pressure and temperature ratings to meet the HPHT specifications of this project. Custom designs will need to be employed, at least on the prototypes. O-rings bear some similarities to high temperature batteries, in that there are o-rings that operate at extremely low temperatures, and o-rings that operate at extremely high temperatures, but it does not appear there are standard formulations that bridge the entire operating temperature spectrum.

Yet another option under evaluation is the applicability of incorporating an active cooling system to allow the use of conventional 300°F power conditioning electronics in high temperature applications. Finite Element Analysis (FEA) using ANSYS Multiphysics is being utilized to determine how and where to channel the borehole heat away from the electronics. Active cooling is inherently inefficient from an output versus power consumption standpoint, but that is an issue that does not negatively impact this particular application. Currently less than 5% of the hydraulic power available in the mud column is being used to drive the turbines in the UnderCurrent design. A secondary generator, or generators, could easily be employed within the tool design to accommodate any additional power requirements related to active cooling.

However, cost has always been an issue raised in low to moderate temperature applications when comparing downhole turbine generator power to battery packs. Cost is a definite consideration for this project, as the intent is to develop a power system that aids in the overall goal of cost viable production of deep, hot hydrocarbons.

In actuality, the cost of battery-powered systems compared to turbine generator power is not what it appears to be at first glance. In addition to the recurring cost of replacing the batteries themselves, there is the initial investment in battery tubes, beryllium copper battery housings, and battery collars. There is shop time required for disassembly, the installation of replacement battery packs, reassembly, and testing. Post replacement, there is the cost and time associated with Environmental Protection Agency (EPA) mandated handling, shipping and disposal of spent cells. There is the also the recurring administrative cost of requisitioning, purchasing, shipping and receiving of the replacement batteries to be considered as well. Downhole battery power for a given tool is actually many times greater than the dollars-per-ampere-hour cost of the battery cells themselves.

It should be noted that downhole turbine generator power does have some similarities to battery power from an overall cost perspective. The generator tool requires its own specialized collar, just as batteries do, and the electrical connectors are identical. Additionally, turbine blades can suffer from erosion from the mud flow. The extent of the erosion and therefore the life of a set of turbine blades is directly related to the mud and drilling conditions. However, the cost of the consumables (turbine blades & bearing sleeves) is lower than a typical battery pack replacement. The initial investment is slightly higher for the turbine generator, but due to the fact that a downhole generator tool is designed to last in the low thousands of hours, the net cost of power per hour is dramatically reduced. It is also a higher density power that can be delivered across the full operating temperature range of the rest of the drill string, and is unencumbered by restrictions on how fast, how heavy and how long you can load it.