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Minimum Formation Damage and Improved Efficiency: A Program Overview**

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Development of Advanced Drilling, Completion, and Stimulation

Systems for Minimum Formation Damage and Improved Efficiency: A Program Overview

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ABSTRACT

The Department of Energy's (DOE) Natural Gas Resource and Extraction Program consists of industry/government co-sponsored research, development, and demonstration (RD&D) projects, which focus on gas recovery from both conventional and nonconventional resources. The Drilling, Completion, and Stimulation (DCS) Project focuses on advanced, non-damaging technology systems and equipment for improving gas recovery from conventional and nonconventional reservoirs. As operators move from development of current day economically attractive gas-field development to the lower permeability geologic regions of domestic onshore plays, increasing the emphasis on minimum formation damage DCS will permit economic development of gas reserves. The objective of the Project is to develop and demonstrate cost-effective, advanced technology to accelerate widespread use and acceptance of minimum formation damage DCS systems. The goal of this product development effort is to reduce costs and improve the overall efficiency of vertical, directional, and horizontally drilled wells in gas formations throughout the U.S.

The current focus of the Project is on the development of underbalanced drilling technology and minimum formation damage stimulation technology concurrently with the appropriate completion hardware to improve the economics of domestic natural gas field development. Ongoing drilling technology projects to be discussed include development of an electromagnetic measurement while drilling system for directional and horizontal drilling in underbalanced drilling applications and the development of a steerable air percussion drilling system for hard formation drilling and improved penetration rates. Ongoing stimulation technology projects to be discussed include introduction of carbon dioxide/sand fracturing technology for minimal formation damage.

INTRODUCTION

Formation damage may be caused by several factors related to production including, filtrate invasion, drilling and completion fluid penetration into the formation, and formation clay structural expansion. A

common cause of formation damage is permeability reduction. This reduction is typically attributed to pore plugging from migration of native clays, formation of precipitates, and injection of fines or solid particles. This paper deals specifically with prevention of formation damage related to well drilling and stimulation practices in naturally fractured formations.

Naturally fractured formations experience near wellbore formation damage due to fluid loss during the horizontal drilling process. Typically the producing formations and natural fractures are exposed to damaging drilling muds and related additives for an extended period of time as the horizontal well is being drilled. Filtrates and aqueous solutions may penetrate the pore space or natural fractures if the well is drilled overbalanced (to control gas influx or drilling fluids penetrate the formation due to lost circulation and fracturing). Water based muds may cause fluid imbibition and capillary retention, impeding the removal of production fluids from the formation; thus, causing a zone of damage around the horizontal wellbore. One option for avoiding formation damage during the drilling process is the use of low density air/inert gas, air-mist, foam aerated/nitrified mud and underbalanced muds as the drilling fluid. These fluids enhance rock cutting removal while avoiding fluid invasion problems due to lost circulation or migration of fluids into the formation due to pressure overbalance between the fluid column and the rock pore pressure. The creative selection of numerous alternative underbalanced fluids beyond the current mud versus air options should be developed.

Formation damage related to the stimulation process is usually associated with fluid selection and the impact on the producing reservoir rocks. A recent survey of the petroleum industry¹ indicated that 51% of operators have stimulation problems associated with formation damage prevention or remediation. More specific problems listed contributing to this formation damage were breaker problems with gels, non-compatibility with formation rock, and water retention problems. Chenevert and Associates² measured the degree of linear core swelling that occurred in Devonian shale

specimens of both organic-rich and organic-lean intervals. Study results concluded that KCl-based stimulation fluids minimized formation damage associated with clay swelling.

Selected low permeability gas formations contain clays which have the ability to absorb polar molecules such as water. In some cases where reservoirs contain 5 to 10% smectite or other swelling clays, clay volume may be doubled or tripled by structural expansion; thus, decreasing the effective porosity and flow capacity. Additionally, when swelling clays are activated this may destabilize the associated non-expanding clays and cause them to migrate. These associated formation damage problems are prevented by avoiding the exposure of the formation to aqueous fluids such as linear or cross-linked water-based gel systems. The most widely used remedy to minimize formation damage due to aqueous fluids is the use of gas based emulsions. The advantage of gas emulsions are their superior fluid rheology properties, rapid clean-up capability due to the energy of the compressed gases, and the low levels of aqueous fluids present to come in contact and damage the formation reservoir rocks. The use of straight inert gases such as nitrogen or carbon dioxide have also been successful for stimulating formations not requiring propping agents to retain fracture conductivity. Production in tight, low permeability formations can be completely blocked if formation pressures do not exceed fluid capillary forces. Komar and Yost found that foam emulsion fracturing fluids appear to be suitable for the Devonian shale formation since the formation is shallow and has low temperature and is low pressure.

An alternative improved stimulation fluid involves the use of carbon dioxide fluid without the presence of aqueous fluids which removes permeability damage related to fluid imbibition and water retention, causing relative permeability reduction. Additionally, polymer gelling agents are not present in the fluid, avoiding the likelihood of fracture conductivity reduction and near wellbore formation damage. The economics of the stimulation are improved due to rapid cleanup and evaluation.

DEVELOPMENT OF NON-DAMAGING DRILLING, COMPLETION, AND STIMULATION PRODUCT SYSTEMS

The DOE Natural Gas program follows the National Petroleum Council (NPC) study recommendations through development of natural gas supply products. Projects are coordinated with activities being sponsored by other funding organizations such as the Gas Research Institute (GRI), and are integrated into product systems that have commercial potential, promote increased natural gas system efficiencies and natural gas market stimulus, and encourage rational exploitation of domestic natural gas supplies.

The mission of the Drilling, Completion, and Stimulation (DCS) product area is to develop and promote recovery systems, which are economically viable, reliable, high efficiency, environmentally acceptable and beneficial to the domestic natural gas industry. The components of the DCS products are drilling surface and subsurface instrumentation and hardware, completion hardware and cementing processes, and stimulation processes. Near term product goals are to evaluate the potential for air drilling technology; identify target reservoirs for development of minimum formation damage DCS products; and demonstrate the use of high efficiency, reduced cost, minimum formation damage DCS product systems. An ongoing product support project focuses on industry cooperative demonstration of advanced non-damaging hydraulic fracture fluid systems. The relationships between DCS projects and product development is given in Figure 1. Figure 2, displays the various locations with application potential for product system field sites throughout the lower 48 U.S.

DRILLING PRODUCT SYSTEMS

Under the DOE/Morgantown Energy Technology Center (METC) DCS Product area, advanced, non-damaging drilling product systems are being developed and commercialized in conjunction with industry partners. The intent of this initiative is to develop new drilling technologies to provide ample, cost-competitive gas supplies from deeper, harder to recover natural gas reservoirs (low permeability or compartmentalized).

The advantages of air drilling are cost reductions associated with increased drilling rates and avoidance of reservoir formation damage due to mud or water invasion. Figure 3, depicts the relationship between various drilling fluid options and drilling time, emphasizing the ability of air drilling fluids to reduce costs while avoiding formation damage. METC is currently evaluating the potential for air drilling technology with a study to determine the marketability of air drilling for tight or hard rock formations. Ongoing drilling technology projects include development of an electromagnetic MWD system for directional and horizontal drilling in underbalanced drilling applications and development of a steerable air percussion drilling system for hard formation drilling and improved penetration rates. The DCS product area will provide the additional insight to develop charts similar to Figure 4 to guide producers in effectively selecting the optimum drilling fluid combination for a given area.

A major effort has been initiated for the development and testing of two complete prototype steerable air percussion drilling systems to be tested in two vertical, two directional, and three horizontal wells in the U.S. over the next 2 years. These products will be the first generation directional percussion drilling system which will be part of a long-term development project for a new integrated air percussion MWD drilling system. This system will be applicable for drilling hard formations containing large quantities of sub-economic gas in low permeability gas reservoirs throughout the U.S. Percussion technology has proven to be more effective for drilling wells in medium to hard rock formations. This is attributed to increased penetration rates from the percussive actions delivered by the downhole hammer and enhanced removal of rock cuttings away from the drill bit face with air as the working fluid. The advanced steerable air percussion drilling system consists of modified enhanced hammer bit, an air hammer containing either rotating the bit and hammer, a modified wireline steering sensor package, one or more special stabilizers, and a single and/or adjustable bend mechanisms. The advantages of this system are the improved directional control equipment for hard rock formations to extend the limits of horizontal drilling and reduce costs of expensive wells. The steerable air percussion system will be the first available product, which will provide the ability to apply directional air percussion methods to avoid formation damage while penetrating the rock formation at high drilling rates.

DOE has completed the first of four field tests using the newly designed electromagnetic MWD tools. The objective of this project is to tool-harden and commercialize a wireless MWD tool for air, air-mist, or air-foam fluids. During October through December of 1989, field tests resulted in two failures attributed to dry-hole conditions and oil lubrication. Since then, these problems have been resolved with power amplifier modifications, substitutions for downhole lubricants, use of longer electrodes, and adding small amounts of water into the drilling process. A third field test was performed, resulting in a transducer twistoff, uphole terminal, and driller's display problems. This problem has been resolved with a redesign and corrective action program. Since these modifications were accomplished, a Model 27 system has been successfully field tested two times and a transducer designed and fabricated. The sixth field test

resulted in a mean-time-between-failure to just under 100 hours. Field test results demonstrated for the first time include a 99 hour mean-time-between-failure-time, which is almost three times better than any previous run. This major milestone is a significant breakthrough for a U.S. based corporation with this type of air MWD capability. When commercialized, this system will provide wireless directional capability for drilling high angle holes or horizontal targets in formations that are amenable to air, air-mist, or air-foam fluids. A schematic of the Model-27 EM MWD drilling system is given in Figure 5.

Future product development efforts will be focused toward (1) underbalanced vertical, directional, and horizontal drilling technologies for conventional hole sizes, to include but not be limited to, air, air-mist, foam, inert gas, natural gas, and aerated mud technologies; (2) vertical, directional, or horizontal slim-hole drilling technology utilizing all types of drilling fluid systems; and (3) low cost drilling rig retrofit equipment that improves rig efficiency. The inherent advantages of these drilling product systems are improved rock penetration rate, reduced lost circulation, lower mud costs, and less formation damage while drilling. The slim hole drilling system is defined as any vertical, directional, or horizontal drilling to a target reservoir with no larger than 4 3/4" wellbore diameter. The primary advantage to the slim hole systems is that they can reduce drilling costs by 40 to 70% due to the use of smaller rigs, higher drilling rates, and reduced casing costs. Slim hole motors are often conveyed down the wellbore using coiled tubing. Many companies market small motors and are pioneering the use of small downhole motors to drill slim holes at high speeds. These motors typically operate at rotary speeds of 500 to 1,000 RPM and drill many formations three to five times faster than rotary rigs. As the need for slim hole drilling hard formations increases, low speed, high torque positive displacement motors and air hammers will be required to drill these slim hole wells.

COMPLETION PRODUCT SYSTEMS

In the completion area, three horizontal wells will be drilled in the Niobrara, Clinton, and Glen Rose formations. The wellbores may be cemented or completed openhole. These industry cooperative projects will provide an opportunity to demonstrate the effectiveness of advanced completion and stimulation techniques for horizontal wells in naturally fractured sandstone and carbonates.

Historically, DOE/METC has performed high-angle and horizontal field tests in the Devonian shale formations.^{5,6} These field tests demonstrated the use of novel techniques for completing these wells to isolate the natural fracture zones. These completion techniques isolate the natural fracture zones with inflatable packers and port collar entry mechanisms. This openhole method avoids formation damage associated with pumping cement between the reservoir rock and the casing and losing cement into the fracture systems.

A horizontal well is being drilled in the Clinton Sand formation, a low permeability, complex sandstone. The project will address three objectives: Evaluate the use of horizontal wells in hard, abrasive formations such as the Clinton; demonstrate the use of hydraulic fracturing from a horizontal well to improve the production performance in this low permeability environment; and determine the effectiveness of additional resource recovery from a complex low permeability "tight sandstone" reservoir. Open hole completion using straddle packers during stimulation is an option.

STIMULATION PRODUCT SYSTEMS

The NPC has emphasized the importance of technology advancement for providing adequate natural gas supplies to meet projected demands. Advances in stimulation technology are a key to unlocking natural

gas resources trapped in high potential, low permeability formations.

In the stimulation component of the DCS product system, near-term advantages are realized through low-cost, non-damaging hydraulic fracturing fluids. Figure 6, displays relationship between various fracture fluids for defining a strategy to select the least damaging and most cost-effective fracturing fluid. Clearly, carbon dioxide and nitrogen foams are the quickest to cleanup after a stimulation and also have the advantage of avoiding formation damage due to water invasion. The use of non-damaging hydraulic fracturing fluids are instrumental in providing productive stimulation treatments for water-sensitive, and/or low pressure gas reservoirs. Non-damaging fluids such as nitrogen and carbon-dioxide based fluids have been successfully used to stimulate water-sensitive coalseams, sandstones, and shales. Another key advantage to non-damaging fluids is retained permeability of the proppant pack in the in situ fracture. This component of the system is significant for all types of reservoirs. Recent developments of water based cross-linked fluids and advanced breakers have been demonstrated in tight sandstone reservoirs. These demonstrations resulted in increased well productivity and reduced stimulation costs compared to the performance of original treatments.

In the DCS product stimulation area, technology applications will focus on minimum formation damage stimulation products. Advanced, non-damaging stimulation systems will be developed and commercialized in conjunction with industry partners. The intent of this initiative is to provide new stimulation technologies to provide ample, cost-competitive gas supplies from low permeability reservoirs. Cost and efficiency will be emphasized during the development of new or advanced technologies. Projects are ongoing and planned to develop advanced stimulation technologies or systems in conjunction with industry.

The use of carbon dioxides as a hydraulic fracturing fluid in the form of an emulsion foam has seen wide spread success. However, the use of carbon dioxide without water or viscosity enhancing gels has not been widely used throughout the domestic industry. DOE sponsored research projects are underway to demonstrate the use of non-damaging proppant-laden carbon dioxide in up to 27 Devonian shale wells.⁷ To date, 12 stimulation treatments have been performed with production responses more than 50% better than alternative methods. These demonstrations incorporate a special blender which allows an operator to fracture treat with straight carbon dioxide and sand, without the potential damaging effects and clean-up expense incurred with water-based fluids. These product field tests demonstrate the benefits of carbon-dioxide stimulation for Devonian shales and promote expansion of this technology to deeper, water-sensitive reservoirs in U.S. basins. In conjunction with the production sector of the industry, eight Devonian shale wells of opportunity have been successfully stimulated with straight carbon dioxide laden with sand propping material. Results to date indicate that the carbon dioxide sand treatments are 56% more efficient than the nitrogen stimulations typically used in Pike County, Kentucky, and 4.8 times better than the conventionally shot wells in the Pike County, Kentucky, study area.

Figure 7, displays preliminary results measured during field tests to evaluate the effectiveness of straight carbon dioxide stimulation fluids.

In addition to the carbon dioxide sandfrac project, DOE currently has an effort addressing the commercialization of TPL stimulation in horizontal wellbores. A GRI/DOE cooperative research program is planned to address research needs of the operators in the Greater Green River Basin (GGRB). In collaboration with the Low Permeability Development Product area, the DCS Product developments will address the needs for demonstration and testing of advanced DCS products for the

GGRB. Collaborative efforts with GRI are ongoing with the Fracture Fluid Characterization Facility (FFCF) and the Hydraulic Fracture Measurement Site. The near-term plan is to develop fluids products to ensure wide-spread availability of advanced hydraulic fracture fluids for U.S. based service companies and operators. By 1997, research focuses on testing of the fluids at the FFCF and in the field to provide credible information on the behavior and rheological properties of these fluids for simulation modeling and treatment design. Mid-term research will support commercialization of tested and demonstrated advanced hydraulic fracturing fluids and stimulation systems for intermediate to deep reservoirs.

DISCUSSION

In the area of reduced formation drilling, results to date indicate that additional minimum formation damage technology development is required to achieve product system development goals and objectives. Additional laboratory and field measurement RD&D for drilling fluid characterization and applications is required to better understand the limitations and benefits of underbalanced fluid systems. Additionally, producers need to be educated and aware of options available for selecting non-damaging fluid systems for drilling.

For stimulation, preliminary evidence indicates that carbon dioxide sandfracturing holds great potential as a non-damaging fluid for formations prone to clay swelling or capillary fluid retention. If tests are successful in eastern Devonian shales formations, this technology will hold significant promise for deep, tight rock formations in western basins.

Future product development efforts will be focused toward (1) vertical, directional, or horizontal slim hole drilling technology utilizing all types of drilling fluid systems; (2) underbalanced vertical, directional, and horizontal drilling technologies for conventional hole sizes, to include but not be limited

to, air, air-mist, foam, inert gas, natural gas, and aerated mud technologies; (3) low cost drilling rig retrofit equipment that improves rig efficiency; (4) minimum formation damage stimulation products; and (5) low cost horizontal completion products.

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Figure 1. Integration of project into drilling, completion, and stimulation products

Demonstration of the Hydraulic Fracturing Process

Demonstration of the Horizontal Drilling Process

Figure 2. Application of product systems in several field sites for technology transfer

Interval	Well A	Well B	Well C	Well C
Surface Hole	0-774' mud	0-725' mud	0-770' mud	0-805' mud
Intermediate Hole	744-2578' mud	725-2510 mud	770-2525' mud	805-1427' air 1427-2507' mud
Production Hole	2578-5008' mud	2510-4000' air	2525-4144' air 4144-5100' mud	2507-4319' air 4319-4650' mud
% Air Drilled	0%	37%	66%	52%

Figure 4. Example of drilling fluid impact on drilling rates in a Southern Oklahoma Province

Figure 3. Strategy for reduced damage drilling

Figure 5. Model-27 Electromagnetic (EM) Measurement-While-Drilling (MWD) System for underbalanced directional drilling

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Figure 6. Strategy for reduced damage stimulation

Devonian Shale Eastern Kentucky Gas Field

Treatment	N ₂ Foam	N ₂ Foam	N ₂ Gas	N ₂ Gas	CO ₂ /Sand	CO ₂ /Sand
Stages	2	2	2	2	2	2
TIL	08/13		08/11	08/11	10/13	10/19
Date	10/08/93		10/08/93	10/08/93	10/28/93	10/28/93
Press	110		110	110	300	100
MCFD	39	——	146	46	235	146
MCFD (AVG)	——	39	——	96	——	190

Figure 7. Post-stimulation production responses to fracturing fluid selection

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