New Technologies for Managing Oil Field Wastes

to be presented by:
John A. Veil
Argonne National Laboratory

at the:
American Society of Mechanical Engineers Energy Technology Conference and Exhibition, Environmental Symposium

February 5-7, 2001
Houston, Texas

DISCLAIMER

New Technologies for Managing Oil Field Wastes

John A. Veil
Argonne National Laboratory
955 L'Enfant Plaza, SW, Suite 6000
Washington, D.C. 20024
202-488-2450
FAX - 202-488-2413
jveil@anl.gov

ABSTRACT

Each year, the oil industry generates millions of barrels of wastes that need to be properly managed. For many years, most oil field wastes were disposed of at a significant cost. However, over the past decade, the industry has developed many processes and technologies to minimize the generation of wastes and to more safely and economically dispose of the waste that is generated. Many companies follow a three-tiered waste management approach. First, companies try to minimize waste generation when possible. Next, they try to find ways to reuse or recycle the wastes that are generated. Finally, the wastes that cannot be reused or recycled must be disposed of.

For the past seven years, Argonne National Laboratory has been evaluating the feasibility of various oil field waste management technologies for the U.S. Department of Energy. This paper provides brief overviews of four of the technologies Argonne has reviewed. In the area of waste minimization, the industry has developed synthetic-based drilling muds (SBMs) that have the desired drilling properties of oil-based muds without the accompanying adverse environmental impacts. Use of SBMs avoids significant air pollution from work boats hauling offshore cuttings to shore for disposal. Downhole oil/water separators have been developed to separate produced water from oil at the bottom of wells. The produced water is directly injected to an underground formation without ever being lifted to the surface, thereby avoiding potential for groundwater or soil contamination. In the area of reuse/recycle, Argonne has worked with Southeastern Louisiana University and industry to develop a process to use treated drill cuttings to restore wetlands in coastal Louisiana. Finally, Argonne has conducted a series of four baseline studies to characterize the use of salt cavern for safe and economic disposal of oil field wastes.

Introduction

Oil field wastes are generated through well drilling, through the process of producing oil and gas, and through associated activities. The drilling process generates two types of wastes -- drilling fluids and drill cuttings. Drilling fluids (or muds) are used to aid the drilling process. Muds are circulated through the drill bit to lubricate the bit and to aid in carrying the groundup rock particles (drill cuttings) to the surface, where the muds and cuttings are separated by mechanical means. Most onshore wells are drilled with water-based or oil-based muds, while offshore wells may also use synthetic-based muds. The American Petroleum Institute (API 2000) estimates that about 150 million barrels (bbl) of drilling waste was generated at U.S. onshore wells in 1995.

When oil and gas are produced to the surface, they are accompanied by formation water known as produced water. Produced water is generally salty and is the largest volume waste stream generated in the oil and gas industry. API (2000) estimates that almost 18 billion bbl of produced water was generated at U.S. onshore wells in 1995.

Various other wastes, known as associated wastes, are generated through the process of collecting, treating, and storing oil and gas. Examples of these wastes are tank bottoms, soil contaminated by spills of produced water or crude oil, spent chemicals used to complete and stimulate wells, and pipe scale and sludges. API (2000) estimates that about 20 million bbl of associated waste was generated at U.S. onshore wells in 1995.

How Are Wastes Managed?

In 1988, the U.S. Environmental Protection Agency (EPA) determined that oil and gas exploration and production wastes (including drilling wastes and produced water) were exempt from the hazardous waste requirements of the Resource Conservation and Recovery Act (RCRA) [53 FR 25477]. In 1993, EPA concluded that associated wastes would also have the same exemption [58 FR 15284]. The federal government determined that state agencies were adequately managing the wastes and did not impose its own regulatory requirements. Therefore, regulation of oil field wastes is done at the state level.

Most onshore oil field wastes are disposed of at the site of the well from which they were generated. Common practices are pit disposal or land spreading of drilling wastes and injection of produced water. At offshore platforms, most produced water and some drilling wastes are discharged to the ocean.

Some wastes are sent to offsite commercial disposal facilities. Veil (1997) describes the various methods used to dispose of oil field wastes at such facilities. Different wastes are managed with different approaches. For example, produced water is most often managed through injection or evaporation, while drilling wastes and associated wastes are managed through a variety of methods, including:

- land spreading
- pits or landfills
- evaporation
- injection
- incineration
- salt caverns
- treatment and reuse

The Waste Management Hierarchy

Historically, oil field wastes were managed in ways that were found to be most convenient or least expensive. Over the past decade, oil and gas operators have looked to waste management approaches that minimize the generation of wastes and to disposal techniques that offer greater environmental protection and public safety. A three-tiered waste management hierarchy is employed. In the first tier, processes are modified, technologies are adapted, or products are substituted so that less waste is generated. When feasible, waste minimization can often save money for operators and results in greater protection of the environment.

For those wastes that remain following waste minimization, operators next move to the second tier, in which wastes are reused or recycled. An example from the oil field is injection of produced water not for disposal but to stimulate secondary production through a water flood. A second example is reuse of treated drill cuttings as landfill cover material.

Some wastes cannot be recycled or reused and must be disposed of by the methods described in the previous section. For some of the disposal options, wastes are treated before disposal.

New Waste Management Approaches

The U.S. Department of Energy (DOE) is responsible for ensuring an adequate and affordable supply of energy for the nation. One of DOE's goals is to identify and support new technologies that help to produce oil and gas at lower cost and with less environmental impact. For the past seven years, Argonne National Laboratory has helped DOE to evaluate the feasibility and effectiveness of innovative oil field technologies. Four of these technologies are described in the following sections. Two of the technologies (synthetic-based muds and downhole oil/water separators) fall into the waste minimization tier. The concept of using treated drill cuttings to restore wetlands falls into the reuse/recycle tier. The final technology described here, placing oil field wastes in underground salt caverns, falls into the waste disposal tier.

Synthetic-Based Muds (SBMs)

Historically, the drilling industry used primarily water-based muds (WBMs) for offshore drilling. WBMs are inexpensive, and the mud and cuttings from wells drilled with WBMs can be discharged from offshore platforms as long as they meet current effluent limitations guidelines (ELGs) discharge standards. However, for difficult drilling situations, such as wells drilled in reactive shales, deep wells, and horizontal and extended reach wells, WBMs do not offer consistently good drilling performance. Until recently, the industry has relied on traditional oil-based muds (OBMs), using diesel and mineral oil, for these more difficult drilling situations. OBMs perform well, but they are harmful to the environment when discharged to the sea. Consequently, the EPA prohibited any discharge of OBMs or their cuttings.

Over the past decade, the drilling industry has developed a new family of fluids using various synthetic organic chemicals as the base fluid. These materials are known as synthetic-based muds (SBMs). In general, SBMs share the desirable drilling properties of OBMs but are free of polynuclear aromatic hydrocarbons, have lower toxicity, faster biodegradability, and lower bioaccumulation potential. For these reasons, SBM cuttings are less likely than OBM cuttings to cause adverse sea floor impacts. EPA has identified this product substitution approach as an excellent example of pollution prevention that can be accomplished by the oil and gas industry. SBMs drill a cleaner hole than WBMs, with less sloughing, and generate a lower volume of drill cuttings. SBMs are recycled to the extent possible, while WBMs are discharged to the sea. Several categories of SBMs, distinguished by the base fluid material used, are commonly available today. The base fluids include linear alpha-olefins (LAOs), poly-alpha-olefins (PAOs), internal olefins (IOs), fatty acid esters, and a host of others. The industry has been eager to use SBMs, particularly in the Gulf of Mexico, where drilling has moved into deep water and hauling of OBM cuttings to shore is difficult and costly. However, during the 1990s, federal regulatory requirements did not adequately address the issue of discharge of cuttings generated while using SBMs.

In the mid-1990s, DOE funded a study by Argonne National Laboratory to evaluate the advantages and disadvantages of the three different types of muds (Burke and Veil 1995). The study pointed out that SBMs offer both significant cost savings for the industry and significant pollution prevention opportunities. In one example discussed in the study, five wells were drilled with WBMs and three wells were drilled with SBMs in the same field. The SBMs consistently outperformed the WBMS -- they drilled at a rate (both feet per day and days to completion) almost three times faster and drilling costs were only about 45% as much. The environment benefited from the use of SBMs as well, because the total volume of used muds and cuttings discharged to the ocean was much lower. SBMs drill a much cleaner hole, resulting in less slumping of the walls and fewer cuttings. When WBMs are used, the volume of cuttings is generally higher because the walls of the hole slump and cave in. Further, WBMs are discharged to the ocean, while SBMs are recycled.

DOE took the lead in promoting the use of SBMs as a pollution-preventing technology and asked EPA to revise and clarify its offshore regulations. EPA recognized the value of SBMs and agreed to participate in a government/industry Synthetic-Based Fluids Discussion Group, organized by DOE. In December 1997, EPA felt strongly enough about the potential of SBMs that it announced that it would actively develop new rules to regulate discharges of cuttings from wells drilled with SBMs. The Discussion Group was reorganized into a steering committee, which included representatives from DOE, EPA, the Minerals Management Service (MMS), and industry (including the American Petroleum Institute, the National Ocean Industries Association, the Petroleum Equipment Suppliers Association, the Offshore Operators Committee, and more than 70 individual companies). The discussion group also established five industry work groups. EPA decided to utilize an innovative expedited rulemaking process that streamlined the regulatory development process from 4-6 years to 2-3 years (Veil and Daly 1999; Veil et al. 1999a). DOE has funded several additional studies by Argonne and Brookhaven National Laboratories that provided data used by EPA in its proposed rulemaking (Gasper et al. 2000; Meinhold 1999; Veil 1998, 1999). DOE has also committed funding to a multiyear sea floor study of environmental fates and effects. The final regulations are scheduled to be completed in late 2000.

In February 1999, EPA published proposed regulations for discharges of SBM-derived cuttings to the ocean [64 FR 5488]. EPA estimated that if offshore wells could be drilled using SBMs rather than OBMs, and SBM-derived cuttings discharges were allowed under the proposed regulations, compared to the existing practice of hauling OBMs back to shore for onshore disposal, there would be a net savings of 380 tons per year of air emissions, 29,000 barrels of fuel for work boats, and 105,000 tons per year of drilling wastes not disposed onshore. As of

October 2000, when this paper was submitted, it appeared that EPA was likely to allow discharges of SBM cuttings in its final regulations.

Downhole Oil/Water Separators (DOWS)

DOWS technology embodies waste minimization because it reduces the quantity of produced water that is handled at the surface by separating it from the oil downhole and simultaneously injecting it underground. A DOWS system includes many components, but the two primary ones are an oil/water separation system and at least one pump to lift oil to the surface and inject the water. Two basic types of DOWS have been developed – one type using hydrocyclones to mechanically separate oil and water and one relying on gravity separation that takes place in the well bore (Veil et al. 1999b-d).

Hydrocyclones use centrifugal force to separate fluids of different specific gravity without using any moving parts. A mixture of oil and water enters the hydrocyclone at a high velocity from the side of a conical chamber. The subsequent swirling action causes the heavier water to move to the outside of the chamber and exit through one end, while the lighter oil remains in the interior of the chamber and exits through a second opening. The water fraction is then injected and the oil fraction is pumped to the surface. Hydrocyclone-type DOWS have been designed with electric submersible pumps, progressing cavity pumps, and rod pumps. Most of the development work on this type of DOWS was done through several joint industry projects by a Canadian organization, CFER-Technologies.

Gravity separator DOWS are designed to allow the oil droplets that enter a well bore through the perforations to rise and form a discrete oil layer in the well. A gravity separator tool has two intakes, one in the oil layer and the other in the water layer. The gravity separator-type DOWS use rod pumps. As the sucker rods move up and down, the oil is lifted to the surface and the water is injected. The most common gravity separator-type DOWS is the dual-action pumping system (DAPS) developed by Texaco. An updated version, known as a triple-action pumping system (TAPS) was tested in 1999 (Wacker et al. 1999).

The cost of lifting, treating, and disposing of produced water is an important component of total operating costs. DOWS can save operators money by reducing produced water management costs. In all of the 29 DOWS installations examined by Veil et al. (1999b) that had both pre- and post-installation data, DOWS reduced the volume of water brought to the surface. The percent reduction ranged from 14% to 97%, with most of those installations exceeding 75% reduction in water brought to the surface.

In over half of the North American wells in which DOWS have been installed, the oil production rates increased following the installation. The percent increase in oil production rates ranged from 11% to over 1,100%, although a few wells lost oil production (Veil et al. 1999b). In some cases where surface processing or disposal capacity is a limiting factor for further production within a field, the use of DOWS to dispose of some of the produced water may allow additional production in that field.

DOWS provide a positive, but unquantifiable, environmental benefit by minimizing the opportunity for contamination of underground sources of drinking water through leaks in tubing and casing during the injection process. Likewise, DOWS minimize spillage of produced water onto the soil at the surface because less produced water is handled at the surface.

Although most of the DOWS installed to date have worked well, some of the installations have experienced problems. The problems can be broken down into several major categories, as noted below:

- Some installations were poorly chosen or designed. Some operators didn't want to risk damaging good performing wells with a new device and thus selected less than optimal candidate wells. Particularly in the earliest installations, many of the DOWS design flaws had not been worked out. Subsequent models avoided some of these flaws.

- Some installations did not allow a sufficient depth differential between the producing and the injection intervals. If isolation between the intervals is not sufficient, the injectate can migrate into the producing zone and then short-circuit into the producing perforations. The result will be recycling of the produced water, with oil production rates dropping to nearly zero.

- Two installations suffered from low injectivity of the receiving zone; in both cases, incompatible fluids contacted sensitive reservoir sands and plugged part of the permeability.

- Several installations suffered from corrosion or scaling. This problem may be a result of incompatible chemistry between the production and injection formations.

- Several other installations had problems with excessive collection of sand that either clogged or eroded the DOWS.

In 1998, DOE offered funds through Argonne National Laboratory to partially defray the costs of up to six DOWS installations. In exchange for the DOE funds, operators would provide performance details on the well for six months following installation. Argonne published the results of the first field trial (Veil 2000) and expects to publish two more sets of field data in the next year.

Restoration of Wetlands Using Treated Drill Cuttings

Much of the southern portion of Louisiana is covered with marshes. Over decades of offshore and coastal oil and gas exploration and production, numerous major and minor channels have been carved into the marsh. In many instances, drilling sites are located in blind drilling slips. As these passages are cut into the marsh, historical water flow patterns change, and the rate of erosion and loss of wetlands increases. An estimated 25 to 35 square miles of wetlands acreage is currently lost in South Louisiana each year (LCWCRTF 1997). Some, but certainly not all, of this wetlands loss can be attributed to oil and gas industry activities.

For most coastal Louisiana wells, drill cuttings are collected and hauled to an onshore disposal facility. This process creates a cost for the operator through disposal fees, transportation, clean up of vessels and containers, and disposal of the resulting washwater. The total disposal cost is generally at least $20 to $30 per barrel of drill cuttings.

In the mid-1990s, Greenhill Petroleum Corporation, an independent oil and gas company, proposed a project to test the viability of using treated drill cuttings as a substrate to restore damaged wetlands. If feasible, this process would provide an excellent opportunity to practice pollution prevention while restoring valuable wetlands acreage at no cost to the State of Louisiana. For perspective, over $226 million of government money was spent on wetland creation and restoration in Louisiana between 1990 and 1997. The proposed process would also allow a waste product to be reused for environmental benefit.

The first part of the proposed project consisted of laboratory tests by researchers at Southeastern Louisiana University (SLU) to determine how well wetland plants would grow in two types of treated drill cuttings and under three different hydrological regimes, followed by a field pilot study. DOE provided funding for the project in 1996. The first round of laboratory studies was completed in 1998 (Shaffer et al. 1998), and additional results were published in 2000 (Hester et al. 2000). Both sets of results showed that treated drill cuttings could support the growth of wetlands plants to a degree comparable to that of dredged sediments, the type of substrate normally used to restore wetlands.

The second part of the project consisted of field trials to demonstrate the feasibility of the approach. Argonne explored a variety of mechanisms to get regulatory approval for the field component of the trial. However, the project team has never been able to obtain the needed approval. Veil et al.(2000a) provide a detailed account of the many steps in the process, beginning when Greenhill applied to the U.S. Army Corps of Engineers (COE) in November 1995 for a Clean Water Act Section 404 permit (required for dredge and fill activities) to create a new area of wetlands, by filling in a former drilling slip in the marsh near Venice, Louisiana. Dredged material was to be used to create berms to form an isolated cell that would then be filled with treated drill cuttings. As part of the Section 404 permit review process, various agencies have the opportunity to comment on the application. In March 1996, the EPA Region 6 NPDES Permits Branch responded to the COE, noting that Greenhill's proposed project would be subject to Section 402 jurisdiction (i.e., the project would need a National Pollutant Discharge Elimination System [NPDES] permit from EPA). EPA further noted that any discharges of cuttings from the proposed project would be covered by NPDES General Permit LAG330000, which prohibits the discharge of drill cuttings to waters of the United States. This ruling created a "Catch 22" situation, under which EPA would require an NPDES permit but would not issue one for the proposed project.

During the past year, Argonne has contacted Mexican and Venezuelan officials to investigate opportunities to conduct field trials in those countries. In addition, Argonne and SLU have collaborated with M-I, a drilling fluids company, to develop new methods to treat the drill cuttings that will stabilize the cuttings to minimize leaching of undesirable constituents and provide a better growth medium for plants. Veil et al. (2000b) describe these more recent activities.

Disposal of Oil Field Wastes in Salt Caverns

In 1995, DOE funded Argonne to investigate the technical feasibility and legality of disposing of oil field wastes in salt caverns. The Texas Railroad Commission requested the research, and early efforts were concentrated on baseline studies on caverns in Texas. The report found that disposal of wastes in caverns was technically feasible and that there were no federal or state legal prohibitions against cavern disposal; however some states may need to revise their regulations to make salt cavern disposal feasible (Veil et al. 1996). A few years later, DOE funded another study to evaluate the feasibility of disposing of naturally occurring radioactive material (NORM) – primarily contaminated pipe scale and tank sludges – in salt caverns (Veil et al. 1998). This study also found that disposal of NORM waste into caverns was feasible. Since the initial feasibility studies on salt cavern disposal and NORM disposal were published, the Railroad Commission has permitted two caverns for disposal of NORM waste.

The use of caverns for oil field waste disposal is dependent on two primary factors – the presence of suitable salt formations and a sufficient volume of oil field wastes to make cavern disposal economical. Currently, Texas, Canada, and several sites in Europe are the only locations that have approved oil field waste disposal in salt caverns. To deal with the potential of cavern leakage, a number of criteria are used in the design and placement of disposal caverns. These criteria include depth, size, distance from drinking water sources, surface development, and monitoring plans.

Salt caverns used for oil field waste disposal are created in salt formations by solution mining. When created, caverns are filled with brine. Wastes are pumped into the cavern under low pressure. Each barrel of waste injected to the cavern displaces a barrel of brine to the surface. The brine is either used as a component in drilling mud or is disposed of to an injection well. Caverns are a good place for disposing of wastes that are oily or contain a high degree of solids. Examples of oil field waste suitable for this practice include drilling muds, drill cuttings, produced sands, tank bottoms, contaminated soil, and completion and stimulation wastes.

DOE funded Argonne to conduct additional baseline studies on cost and risk of cavern disposal. The cost study (Veil 1997) found that disposal in caverns could compete economically with other types of waste disposal methods used in the same geographic areas. Costs for oil field waste disposal in caverns in Texas were compared to costs for disposal in other types of commercial disposal facilities. Figures for 1997 indicate that costs for disposal in salt caverns in Texas range from $1.95 to $6.00 per barrel of waste. Other methods (evaluated as cost per barrel) used in the Texas and New Mexico area include land spreading ($5.50 - $16.00), landfill or pit disposal ($2.25 - $ 3.25), evaporation ($2.50 - $ 2.75), and treatment and injection ($8.50 - $11.00).

An additional aspect of oil-field waste disposal in salt caverns is evaluating the processes that may affect the cavern over time. Once a cavern has been filled with waste, any oily layer floating on the top surface is removed and the well leading to the cavern is plugged permanently, sealing the cavern. Internal pressure will increase after sealing because of deformation of the salt deposit under the weight of overburden rock. As the salt flows into the cavern, a process known as salt creep, the volume of the cavern is reduced. Geothermal energy in the rocks may cause the waste contents to expand. Both are very slow processes, and as the fluid pressure increases, the cavern may reach a point that the cavern walls crack or leak, or the waste materials might migrate into the salt formation.

Since no disposal caverns have been closed anywhere in the world, no data are yet available on cavern behavior following closure. Argonne's risk study (Tomasko et al. 1997) identified several scenarios under which a disposal cavern could leak or fail. These include:

- Cavern intrusion, in which a new well is inadvertently drilled into the cavern;
- Failure of the cavern seal at the well bore plug or casing seat;
- Loss horizontally through cracks in the salt or in anhydrite layers; and
- Collapse of the cavern roof.

The estimated probability of these releases ranges from 10^{-3} to 10^{-7}. The modeling used in the risk study focused on four pollutants of concern — arsenic, benzene, cadmium, and chromium — and evaluated the fate and transport of pollutants as they move from the site of the leak to the human receptor, in this case, through a drinking water supply.

The estimated cancer and noncancer risks range from 1.1×10^{-8} to 1.7×10^{-12}. The acceptable threshold for excess cancer risk used by EPA is 10^{-6}. Noncancer risks range from 7×10^{-4} to 7×10^{-9}. The acceptable noncancer risk threshold is 1.0.

Additional laboratory and field research continues to study the effects of pressure rise in oil field wastes disposed of in salt caverns. The Solution Mining Research Institute oversaw preparation of a bibliography for cavern behavior following plugging, including salt creep and rock strength behavior, the permeability of rock salt, temperature and pressure build up, and plugging and sealing issues (Crotogino et al. 1997).

Salt caverns represent an alternative, cost-effective method for disposal of oil field waste. Because the wastes are placed deep into the earth, they are much less likely to affect drinking water supplies than are more traditional waste disposal methods. Up-to-date information on salt caverns can be found at the Salt Cavern Information website (www.npto.doe.gov/saltcaverns).

Conclusions

Many technologies and methods exist for managing wastes. Some approaches provide opportunities for lower environmental impact and lower costs. Four such technologies that are being used or are being considered for use in the oil and gas industry are described here. In some cases, the existing regulations have not envisioned the new approaches and technologies, and regulatory agencies are either unable or reluctant to allow deployment of the new methods. DOE has funded investigations into the merits of these four technologies, all of which offer greater environmental protection.

Acknowledgments

This work was supported by DOE's Office of Fossil Energy and National Petroleum Technology Office under contract W-31-109-Eng-38. Nancy Johnson of the Office of Fossil Energy and John Ford and Nancy Comstock of the National Petroleum Technology Office have been very supportive of Argonne's investigations on these technologies. Many other researchers, including the co-authors of the cited references, contributed to a better understanding of the technologies described here. Robert C. Ayers, Jr. provided a valuable technical review of this paper.

References

API, 2000, "Overview of Exploration and Production Waste Volumes and Waste Management Practices in the United States," prepared by ICF Consulting for the American Petroleum Institute, May.

Burke, C.J., and J.A. Veil, 1995, "Potential Environmental Benefits from Regulatory Consideration of Synthetic Drilling Muds," Argonne National Laboratory Technical Memorandum ANL/EAD/TM-43, February.

Crotogino, F., C. Behrendt, and J. Hackney, 1997, "Bibliography for Cavern Abandonment," report # 97-0002-SMRI, prepared by KBB and PB-KBB for the Solution Mining Research Institute.

Gasper, J.R, J.A. Veil, and R.C. Ayers, Jr., 2000, "Information on Commercial Disposal Facilities That May Have Received Offshore Drilling Wastes," prepared by Argonne National Laboratory for U.S. Department of Energy, Office of Fossil Energy and U.S. Environmental Protection Agency, Engineering and Analysis Division, July.

Hester, M.W., G.P. Shaffer, J.M. Willis, and D.J. DesRoches, 2000, "Restored Drill Cuttings for Wetland Creation: Results of a Mesocosm Approach to Emulate Field Conditions under Varying Salinity and Hydrologic Conditions," prepared by Southeastern Louisiana University Department of Biological Sciences, Hammond, LA, for U.S. Department of Energy, National Petroleum Technology Office, April 26.

LCWCRTF, 1997, "The 1997 Evaluation Report to the U.S. Congress on the Effectiveness of Louisiana Coastal Wetland Restoration Projects," prepared by the Louisiana Coastal Wetlands Conservation and Restoration Task Force.

Meinhold, A.F., 1999, "Framework for a Comparative Environmental Assessment of Drilling Fluids Used Offshore," SPE paper 52746, presented at the 1999 SPE/EPA Exploration and Production Environmental Conference, Austin, TX, February 28 - March 3.

Shaffer, G.P., M.W. Hester, S. Miller, D. J. DesRoches, R.F. Souther, G.W. Childers, and F. M. Campo, 1998, "Restored Drill Cuttings for Wetlands Creation: Results of a Two-Year Mesocosm Approach to Emulate Field Conditions under Varying Hydrologic Regimes," prepared by Southeastern Louisiana University Wetlands Restoration Laboratory, Hammond, LA, for U.S. Department of Energy, National Petroleum Technology Office, July 27.

Tomasko, D., D. Elcock, J. Veil, and D. Caudle, 1997, "Risk Analyses for Disposing Nonhazardous Oil Field Wastes in Salt Caverns," prepared by Argonne National Laboratory for DOE Office of Fossil Energy, December.

Veil, J.A., 1997, "Costs for Offsite Disposal of Nonhazardous Oil Field Wastes: Salt Caverns versus Other Disposal Methods," prepared for DOE Office of Fossil Energy (April 1997); also published by DOE - National Petroleum Technology Office as DOE/BC/W-31-109-ENG-38-3, DE97008692, September.

Veil, J.A., 1998, "Data Summary of Offshore Drilling Waste Disposal Practices," prepared by Argonne National Laboratory for U.S. Environmental Protection Agency, Engineering and Analysis Division, and U.S. Department of Energy, Office of Fossil Energy, November.

Veil, J.A., 1999, "Update on Onshore Disposal of Offshore Drilling Wastes," prepared by Argonne National Laboratory for U.S. Department of Energy, Office of Fossil Energy, November.

Veil, J.A., 2000, "Summary of Data from DOE-Subsidized Field Trial #1 of Downhole Oil/Water Separator Technology - Texaco Well Bilbrey 30-Federal No. 5, Lea County, New Mexico," prepared by Argonne National Laboratory for U.S. Department of Energy, National Petroleum Technology Office May.

Veil, J.A., and J.M. Daly, 1999, "Innovative Regulatory Approach for Synthetic-Based Muds," SPE paper 52737, SPE/EPA Exploration and Production Environmental Conference, Austin, TX, February 28 - March 3.

Veil, J., D. Elcock, M. Raivel, D. Caudle, R. Ayers, and B. Grunewald, 1996, "Preliminary Technical and Legal Evaluation of Disposing of Nonhazardous Oil Field Waste into Salt Caverns," prepared for DOE Office of Fossil Energy, June.

Veil, J.A., K.P. Smith, D. Tomasko, D. Elcock, D.L. Blunt, and G.P. Williams, 1998, "Disposal of NORM-Contaminated Oil Field Waste in Salt Caverns," prepared by Argonne National Laboratory for DOE National Petroleum Technology Office, August.

Veil, J.A., J.M. Daly, and N. Johnson, 1999a, "EPA Expedites Offshore Regulations for Synthetic-Based Mud," *Oil and Gas Journal*, September 13.

Veil, J.A., B.G. Langhus, and S. Belieu, 1999b, "Feasibility Evaluation of Downhole Oil/Water Separation (DOWS) Technology," prepared by Argonne National Laboratory, CH2M-Hill, and Nebraska Oil and Gas Conservation Commission for U.S. Department of Energy, Office of Fossil Energy, National Petroleum Technology Office, January.

Veil, J.A, B.G. Langhus, and S. Belieu, 1999c, "Downhole Oil/Water Separators: An Emerging Produced Water Disposal Technology," SPE # 52703, presented at the SPE/EPA Exploration and

Production Environmental Conference, Austin, TX, March 1-3.

Veil, J.A., B.G. Langhus, and S. Belieu, 1999d, "DOWS Reduce Produced Water Disposal Costs," *Oil and Gas Journal*, March 22, pp. 76-85.

Veil, J.A., N. Johnson, and J.K. Ford, 2000a, "Restoration of Coastal Wetlands Using Treated Drill Cuttings," SPE # 61097, Society of Petroleum Engineers International Conference on Health, Safety, and the Environment, Stavanger, Norway, June 26-28.

Veil, J.A., M. Hester, G. Shaffer, J. Candler, and W. Marchbanks, 2000b, "Further Studies on the Feasibility of Using Treated Drilling Wastes to Restore Wetlands," 7th International Petroleum Environmental Conference, Albuquerque, NM, November 7-10.

Wacker, H.J., R.M. Parker, L. Stuebinger, R. Harding, and B. Watson, 1999 , "Test Proves Out Triple-Action Pump in Downhole Separation," *Oil and Gas Journal*, October 4, pp. 49-55.