Annotated Bibliography of Waste Minimization Technology

For Crude Oil and Natural Gas Exploration, Production, and Pipeline Transportation Operations

RAILROAD COMMISSION OF TEXAS

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INTRODUCTION

The Railroad Commission's Waste Minimization Program (the Program) has reviewed many technical papers and articles to identify technologies which may help reduce waste generation in oil and gas exploration, production, and pipeline transportation operations. The Program has compiled the results of this review into this annotated bibliography. The bibliography is intended to provide oil and gas operators with easy access to references that may provide the information they need to be successful in their waste minimization efforts.

You may note that many references in this first edition are dated prior to 1997. The Program is actively reviewing more recent technical papers and articles. We will periodically update the bibliography. Our goal is to bring the bibliography up-to-date as soon as possible.

References are listed in chronological order. In some instances, references (usually more recent papers) have not been annotated, but the abstract is provided.

In many instances, a technical paper or article indicates that the subject technology was implemented to improve efficiency or to reduce operating costs. Though not emphasized by the authors, these technologies actually result in waste minimization.

Numerous references are available on the Internet. When possible, the URL for the reference is provided. Internet links were checked for validity April 15, 2004. See tips for accessing referenced web sites on the following page. Also, note that the referenced sources of papers and articles are available at many college and university libraries.

The larger portion of the cited references are technical papers published by the Society of Petroleum Engineers (SPE). SPE members are actively involved in developing new procedures, equipment, and products that result in improved E&P operations. Many of the innovations described in SPE papers also provide waste minimization benefits. SPE technical papers are available for purchase on the SPE website at www.spe.org.

Users of this bibliography are encouraged to provide comment to the Program. We also encourage users to offer suggestions for additions to the bibliography. Please direct any comments or suggestions to:

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Certain company and product names furnished by authors appear in this Annotated Bibliography. The reference to any specific brand name, product, vendor, or any other company is not and should not be interpreted as an endorsement by the Railroad Commission of Texas.

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Integrated Petroleum Environmental Consortium (IPEC)

IPEC provides the proceedings of the International Petroleum Environmental Conference. Proceedings are available for all conferences held since 1997. To access conference proceedings, go to the IPEC web site at http://ipec.utulsa.edu/; select "Site Map"; then select "Archive of Previous Conference Proceedings."

Pipeline and Gas Industry

This magazine is available at http://www.pipe-line.com/. To access referenced articles, select "Archive"; then the article date.

Rocky Mountain Oilfield Testing Center (RMOTC)

The RMOTC web site is at http://www.rmotc.com/index.html. Select "Library" for test reports.

Society of Petroleum Engineers (SPE)

SPE technical papers are available for purchase on the SPE web site at http://www.spe.org. Select "eLibrary"; then place cursor over "eLibrary (Papers)" and select "Search eLibrary." Note that you will be asked to register as a guest if you are not a member of SPE. Find the paper of interest by entering the paper number and the page will give you the option to purchase.

World Oil Magazine

The specific URL for the case histories from *World Oil Magazine* Petroleum Technology feature is www.worldoil.com. To access all case histories: select "World Oil Magazine" at the top of the page; then select "Supplements"; then select the desired issue date under "Petroleum Technology."

ACRONYMS

API	American Petroleum Institute
BLM	U.S. Bureau of Land Management
BTEX	Benzene, Toluene, Ethylbenzene, Xylenes
CHOA	Canadian Heavy Oil Association
CAA	Clean Air Act
CFR	Code of Federal Regulations
EPA	U.S. Environmental Protection Agency
GRI	Gas Research Institute (now the GTI)
GTI	Gas Technology Institute
HAP	Hazardous air pollutant
IC	Internal combustion
NPDES	National Pollutant Discharge Elimination System
PS-CIM Petroleum	Petroleum Society - Canadian Institute of Mining, Metallurgy &
PTTC	Petroleum Technology Transfer Council
RCRA	Resource Conservation and Recovery Act
RMOTC	Rocky Mountain Oilfield Testing Center
SPE	Society of Petroleum Engineers
USFWS	U.S. Fish and Wildlife Service

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SECTION 1

IMPLEMENTING EFFECTIVE WASTE MINIMIZATION IN CRUDE OIL AND NATURAL GAS EXPLORATION, PRODUCTION, AND PIPELINE OPERATIONS

Staff members of numerous companies and organizations have authored papers and articles which provide a broad view of waste management and environmental issues in oil and gas operations. They discuss issues such as the implementation of environmental management systems (EMS). In some instances, authors describe how EMS is integrated into a more comprehensive Environmental, Health, and Safety Management Plan (EHSMP). In each instance, waste minimization is an integral part of the plan. Other papers and articles address issues also important to operators interested in implementing effective waste minimization plans. Subjects include waste inventory and tracking and, of great importance, training.

Many small oil and gas companies may not have the time and resources to design and implement EMSs or EHSMPs. In any case, such operators may achieve benefits by identifying and implementing waste minimization techniques. The remaining sections of this annotated bibliography refer to many papers and articles, which provide examples of waste minimization opportunities.

Section 1 provides references to technical papers and articles which address the following:

1.1 Environmental Management Systems

1.2 General Discussions on Waste Minimization

1.3 Inventory and Waste Data Management

1.4 Training

1.1 ENVIRONMENTAL MANAGEMENT SYSTEMS

Abernathy, S.E., and Knode, T.L., "Creation of an Integrated Management System," SPE 66582 presented at the SPE/EPA Exploration and Production Environmental Conference, San Antonio, TX, February 26-28, 2001

This paper presents Halliburton's development of a management system which integrates quality control with health, safety, and environmental management. In developing the system Halliburton assured that all elements of quality management and various environmental management systems (e.g., E&P Forum, ISO 9000, and ISO 14001) were integrated. The authors provide a thorough discussion of the system's development, which may be helpful to others interested in developing an environmental management system. Although waste minimization is not addressed in the paper, it would have a place in an effective integrated management system.

Cross, E.P., "Using Environmental Training and Education as Tools for Optimizing Regulatory Compliance and Enhancing Operating Efficiencies," Proceedings of the 7th International Petroleum Environmental Conference, Albuquerque, NM, November 7-10, 2000

This paper provides guidance on developing a structured, effective environmental training program. The author explains the need for training and education, citing needs such as improved regulatory compliance and reduced incidents of accidents and spills. He provides a fairly lengthy discussion of a systematic approach to training, which requires six phases: analysis, design, development, implementation, evaluation, and documentation/record keeping. The paper includes a case history of an oil field service company's development and implementation of an environmental training program. The company's investment in training resulted in fairly significant economic return and improved its competitiveness. Cost savings included reduced insurance premiums and reduced regulatory noncompliance penalties. This paper is a good reference for company management interested in developing and implementing an environmental training program.

Cross, E.P., "Strategic Environmental Management and Controls for the Independent Oil Producer," Proceedings of the 6th International Petroleum Environmental Conference, Houston, TX, November 16-18, 1999

The author provides an argument for proactive environmental management through strategic long-term planning. His primary point is that total cost accounting over the long term can provide a good economic return as well as environmental protection. A case study of the planning of an enhanced recovery (water flood) project is presented. In the case study a Class II injection well was to be completed The author discusses how economic analysis demonstrated that higher up-front capital costs (e.g., for better quality tubing and equipment) resulted in a profit over the life of the project versus a loss for well completion with lower costs and immediate cost-effectiveness. He also discusses the value of training as a part of environmental management and strategic planning. This paper is useful to operators who wish to combine profitable operations with improved environmental performance.

This paper is available at http://ipec.utulsa.edu/.

Chastain, B., et al, "Applying the ISO EMS Standard to Petroleum Exploration & Production Operations," Proceedings of the 6th International Petroleum Environmental Conference, Houston, TX, November 16-18, 1999

This paper is particularly useful, because the authors discuss the implementation of an EMS (ISO 14001) in an E&P company. The authors provide a very good overview of BP Exploration (Alaska) Inc.'s (BPXA's) ISO 14001 implementation process and the resulting associated benefits. Benefits included cost savings through pollution prevention (e.g., waste minimization) and streamlined business processes, improved regulatory compliance, and enhanced public confidence. The authors acknowledge that BPXA has greater internal resources, but argue that

even a small independent operator can successfully implement an EMS. They offer some "lessons learned" in the process and note that the process was less onerous than anticipated. This paper is a very good reference for any E&P company considering implementation of an EMS.

This paper is available at http://ipec.utulsa.edu/.

Weinrach, J.B., et al, "Pollution Prevention/Best Management Practices Training Manual for the New Mexico Oil and Gas Industry," SPE 52678 presented at the 1999 SPE/EPA Exploration and Production Environmental Conference, Austin, TX, February 28-March 3, 1999

The authors provide a thorough summary of a manual prepared by the New Mexico Energy, Minerals, and Natural Resources Department' Oil Conservation Division (OCD). The two-volume manual includes guidance on preparing a pollution prevention-based environmental management system using a systems approach. A systems-based approach emphasizes building a pollution prevention team, mapping processes, performing activity-based costing, performing root cause analysis, and identifying and prioritizing alternatives. The manual includes source reduction and recycling opportunities. The goal is the development of an action plan which is continuously improved and which achieves economical benefits as well as environmental benefits.

Note: Even though the manual ("Pollution Prevention Best Management Practices") was prepared for New Mexico oil and gas operators, it is a very useful tool for operators anywhere. The manual is available on the OCD web site at www.emnrd.state.nm.us/ocd/. Also, a "Pocket Guide" is available. The "Pocket Guide" lists source reduction and recycling alternatives and is designed for use in the field.

Gorman, S., and McVaugh, J., "Utilizing an Environmental management System for Pollution Prevention Program Sustainability in the Oil & Gas Industry," Proceedings of the 5th International Petroleum Environmental Conference, Albuquerque, NM, October 20-23, 1998

This paper focuses primarily on ISO 14001 and the registration process. The authors note that the diffuse nature of oil and gas operations may make it difficult to implement a sustainable pollution prevention program. Although, they suggest ISO 14001 may be a useful tool, the authors do not discuss ISO 14001 in the context of such operations. But, they do provide a thorough discussion of the elements of an ISO 14001 EMS and the registration and accreditation process.

This paper is available at http://ipec.utulsa.edu/.

Martin, R., ISO 14001 Guidance Manual, Technical Report NCEDR/98-06, National Center for Environmental Decision-Making Research (1998)

This guidance may be useful to operators interested in developing an EMS. The manual states its purpose: "This manual has been developed and organized to assist all interested organizations in the development of an Environmental Management System (EMS) that is consistent with the ISO 14001 Standard, achieves EMS Registration, and improves the overall environmental performance of the organization. Because each organization is different, NCEDR has tried to create a document that is specific enough to give the tools needed to set up and implement an EMS, but general enough to allow the flexibility for addressing unique characteristics." The manual (pdf) may be downloaded at no charge from http://www.ncedr.org/guides/iso.htm.

Pratt, M.D., "Development of ADCO's Environmental Management System," SPE 36270 presented at the 7th ADIPEC, October 13-16, 1996

The author describes the step-by-step development of an EMS, or environmental management system. The EMS was developed for the Abu Dhabi Company for Onshore Oil Operations (ADCO). ADCO selected the BS 7750 EMS model (others include ISO 14000, E&P Forum, and EMAS). As in all EMSs, waste management and minimization is a critical element of the plan. One important aspect of ADCO's development of an EMS is the evidence that environmental performance is becoming a more important issue. ADCO began their EMS at a time when environmental regulations in their area of operation were minimal.

Garland, E., "Environmental Performance Indicators: A Survey of Their Actual Use in the E&P Industry and of Their Foreseeable Development," SPE 36161 presented at the International Conference on Health, Safety & Environment, New Orleans, Louisiana, June 9-12, 1996;

Refsnes, K., PhD, and Kjeelaas, A.G., PhD, "Environmental Performance Indicators With Emphasis on ISO Development and Application in Oil Industry," SPE 36160 presented at the International Conference on Health, Safety & Environment, New Orleans, Louisiana, June 9-12, 1996; and

Jones, M.G., et al, "Environmental Performance Indicators – the Line and Management Tool," SPE 35953 presented at the International Conference on Health, Safety & Environment, New Orleans, Louisiana, June 9-12, 1996

The three papers cited above discuss the development and (internal and external) use of environmental performance indicators. As the authors note, such indicators are a necessary part of an overall environmental management system. In order to achieve effective waste minimization, a company can benefit from evaluating indicators and designing the system to achieve targets. The indicators can also provide additional justification for waste minimization investment. Indicator categories would include emissions to air, energy and resource consumption, discharges to sea, waste generation, and accidental releases/oil spills. The authors

provide additional measures as well (e.g., those that show the impact of an EMS on finances and commercial advantage).

Nyvik, R.O., and Bogwald, S., Implementation of E&P Forum Health, Safety and Environmental Management," SPE 35888 presented at the International Conference on Health, Safety & Environment, New Orleans, LA, June 9-12, 1996

This paper presents a North Sea company's use of the E&P Forum recommended HS&E Management System. The authors provide a thorough discussion of all aspects of the system. The system includes waste minimization goals. The authors note that the company had achieved significant waste minimization after adopting the system, such as reduced CO_2 and NO_x emissions, reduced drilling waste generation, and reduced hazardous waste generation.

Carley, J.A., et al, "Total Quality Management: Integrating Environmental and Quality Management Systems," SPE 35855 presented at the International Conference on Health, Safety & Environment, New Orleans, Louisiana, June 9-12, 1996

The authors discuss the results of combining EMS and Quality Management into one group to assess all aspects of EH&S and the company's quality control process. The TQEM system resulted in benefits to the company, mainly by streamlining procedures to address environmental and quality performance. The authors describe their assessment of the various EMSs. In this instance, the company is Schlumberger, an E&P service company; therefore, their environmental and quality issues vary a bit from those of E&P companies. However, this paper still is a good resource for E&P companies seeking to develop similar systems. Of particular interest, the authors provide examples of TQEM success. An example was investment in a lube oil recycling system (a $14,000 capital expenditure). Rather than spend $1,800 a month on new oil, their used oil was recycled on-site. The result was a 75% reduction in new oil purchases and the investment being recovered within one year. Any company can duplicate this waste minimization project.

Clement, D.L., et al, "Business Integration of Safety, Health, and Environmental Management," SPE 35852 presented at the International Conference on Health, Safety & Environment, New Orleans, Louisiana, June 9-12, 1996

This paper provides yet another example of a company (Caltex) recognizing the value of EH&S and TQ management which includes EMS. Caltex operates outside the U.S.; therefore, a reason for their EH&S project may be regulatory pressure by foreign countries, particularly in the North Sea area. However, all E&P companies can benefit by developing and implementing EH&SM systems. In the case of Caltex, "the company reorganized itself from a functionally-based organization to a team-based organization structured around asset value optimization that instills ownership at the field level." The company's policy includes: "(p)revent the discharge of oil and other hazardous substances; and "(c)onserve natural resources by prudent management of emission and discharges and by eliminating waste," which are goals of waste minimization.

The authors also reference SPE 35768 (below), which describes the training program developed as part of the management system.

Moreau, R.L., and Raught, D.L., "Keys to Improving Environmental Performance," SPE 35762 presented at the International Conference on Health, Safety & Environment, New Orleans, Louisiana, June 9-12, 1996

The authors discuss Exxon's program to improve environmental performance beyond regulatory compliance. The authors describe Exxon's Operations Integrity Management System (OIMS), which follows the API Step Program. Exxon recognizes that waste minimization is the "first priority" in waste management and cite the waste management hierarchy. Also, Exxon emphasizes "every employee's responsibility in environmental performance." The authors list some of Exxon's waste minimization ideas, which include: 1) improved inventory control to make use of surplus chemicals and to reduce chemical waste; 2) product substitution (less toxic chemicals); 3) reuse of spent paint solvents on-site; and 4) use of alternatives to sandblasting (e.g., hydroblasting). Another part of the system is improved preventive maintenance to reduce oil spills (specific initiatives are listed). Exxon distributed a waste management guidance manual to employees to assist them in improved waste management and minimization.

Downey, I.L., "E&P FORUM Health, Safety and Environmental Management System Guidelines," SPE 30390 presented at the SPE Offshore Europe Conference, Aberdeen, United Kingdom, September 5-8, 1995

The author summarizes the E&P Forum's HS&EMS guidelines. This paper would be useful to a company desiring to establish an integrated management system. The E&P Forum, now known as the International Association of Oil and Gas Producers (IAOGP), is based in London. OGP offers the Health, Safety and Environmental Management System Guidelines on their website at http://www.ogp.org.uk/index.html. It can be downloaded free in PDF (the specific URL is http://www.ogp.org.uk/pubs/210.pdf). The IAOGP also offers other useful publications related to waste management, EMS, and emissions reduction (e.g., flaring).

Haffner, D.J., "The Environmental Compliance Audit and Its Cost," SPE 23917 presented at the 1992 IADC/SPE Drilling Conference, New Orleans, LA, February 18-21, 1992

This paper presents a decision making flow chart for use in preparing, conducting, evaluating, and responding to an environmental compliance audit. The model incorporates environmental issues typical of an oil and gas equipment storage facility. Although the paper focuses on regulations and compliance, the author briefly discusses the role of waste minimization.

Cline, J.T., and Førde, R., "Environmental Program With Operational Cases To Reduce Risk to the Marine Environment Significantly," SPE 23329 presented at the First International Conference on Health,, Safety and Environment, The Hague, The Netherlands, November 10-14, 1991

This paper details Amoco Norway's environmental program. Issues discussed include: 1) the integration of environmental goals, mission and strategies into the strategic business plan; 2) the environmental management/quality assurance plan; 3) the Waste Task Force which addresses issues to meet specified environmental requirements; and 4) achievements and activities of the environmental program (including specific examples of waste minimization). This environmental program was designed for operations in the North Sea; however, many of the principles presented could be applied in any operation.

Kwant, J.W.H., and Grant, R.O.H., "Environmental Performance Management: The Next Step," SPE 23317 presented at the First International Conference on Health,, Safety and Environment, The Hague, The Netherlands, November 10-14, 1991

This paper describes the environmental program developed by Shell U.K. E&P (EXPRO) aiming at continuous improvement of its environmental performance. The program includes an inventory of all gaseous emissions, liquid effluents and solid waste discharges (waste streams) during a baseline year (1989). The inventory was used to identify the largest waste streams and to set priorities for the subsequent waste minimization program. Shell U.K. EXPRO operates primarily in the North Sea; however, the principles applied in their environmental performance management program can be transferred to any operation.

Jennett, L.E., "A Better Environmental Management System," SPE 22819 presented at the 66th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Dallas, Texas, October 6-9, 1991

This paper is an early attempt to raise the industry's awareness of the importance of an integrated EMS. The author recognized the need for "long range planning for environmental management for the next decade." Numerous SPE papers on the subject in the following years showed that EMS was an important part of a business plan. The author makes the point that an effective EMS is proactive and systematic – it replaces "damage control." Roadblocks which companies need to remove are lack of field personnel knowledge (e.g., regulations and best management practices), resource limitations, and limited authority to implement necessary actions. The author recognizes that a consistently applied EMS can help a company demonstrate environmental accountability to regulators and the public. For example, measurement of waste minimization and documentation of waste minimization are examples of quantitative mechanisms used to provide accountability.

1.2 GENERAL DISCUSSIONS ON WASTE MINIMIZATION

Roberson, D.R., "Minimizing E&P Liability at Superfund Sites," SPE 66518 presented at the SPE/EPA Exploration and Production Environmental Conference, San Antonio, TX, February 26-28, 2001

Although this paper only briefly addresses waste minimization, it does note its importance in overall waste management planning. The author primarily discusses oil and gas waste management pitfalls which may expose an operator to liability for remediation of operational and disposal sites. Many common-sense practices are discussed, including waste segregation and careful planning of operations conducted by service companies. This paper provides a discussion of potential future liability, which is an incentive for practicing waste minimization. (Note that the author incorrectly implies that spent amine and glycol generated at gas plants "generally become hazardous waste." These wastes are exempt from being hazardous waste under 40 CFR 261.4(b)(5).)

Mesing, G.E., et al, "Assessment Methodology and Results for Waste Minimization in the Natural Gas Industry," SPE 37888 presented at the 1997 SPE/EPA Exploration and Production Environmental Conference, Dallas, TX, March 3-5, 1997

The authors present the results of a Gas Research Institute (GRI)-sponsored assessment of waste minimization alternatives. The authors discuss the methodology used to prioritize wastes generated in natural gas drilling, production, processing, and pipeline transportation. The study identified numerous waste minimization techniques for the higher priority wastes. As a part of the study, the authors developed an economic analysis computer model, "GRI WMIN-Econ." The model was used to determine the potential for certain waste streams to be economically minimized. The paper offers numerous ideas for minimizing oil and gas waste. Although the study was directed at wastes generated by the natural gas industry, much of the material presented may be applied to all E&P operations.

Note: This study resulted in the GRI's (now the Gas Technology Institute) publication of "Waste Minimization in the Natural Gas Industry: Regulations, Methodology, and Assessment of Alternatives" (GRI-97/0252). This book, which includes the GRI WMIN-Econ software on diskette, may be ordered from GTI on their web site at www.gri.org.

McFadden, U., "Waste Management Development in the Oil and Gas E&P Industry," SPE 36188 presented at the 7th Abu Dhabi International Petroleum Exhibition and Conference, Abu Dhabi, October 13-16, 1996

The author describes Total Marine Plc.'s efforts to implement a waste management program. Total Marine began with waste inventory and segregation. The author emphasizes that source reduction and recycling opportunities may be more efficiently addressed once the types, quantities, and frequencies of waste generation are understood and documented. The author also stressed the role all employees have in making a waste management and minimization plan

work. In summary, the paper presents an excellent case for developing plans which identify waste disposal as an issue and designate responsibilities at all levels.

Rowell, D., and Benton, J.H., "Putting Environmental Technology to Work for Independents," SPE 35835 presented at the International Conference on Health, Safety & Environment, New Orleans, Louisiana, June 9-12, 1996

The authors describe the creation and purpose of the Petroleum Technology Transfer Council (PTTC). An emphasis of the PTTC is providing independents with access to technologies that can help reduce the cost of environmental and regulatory compliance. Included in the PTTC's main mission is to transfer technologies that will improve operating efficiency and enhance environmental compliance. Waste minimization technologies have a role in the PTTC mission. With respect to waste minimization, PTTC has focused primarily on energy efficiency and cost reduction (e.g., electric power costs).

Bulovas, B.J., "Environmental Target Setting and Ranking, " SPE 35831 presented at the International Conference on Health, Safety & Environment, New Orleans, Louisiana, June 9-12, 1996

The author describes a methodology for ranking "environmental projects" to reduce discharges to the environment. The methodology, "ETSR" (Environmental Target Setting and Ranking), focuses on projects that are not regulatory-driven or do not offer an economic return. ETSR uses the Pareto Principle and the bubble-up algorithm, similar to the NMOGD's planning steps. The ETSR approach is to establish a 10-year plan for established environmental discharge objectives and work towards the objectives using available budget for the projects. The 10-year window provides flexibility.

Parnell, J.A., and Herlugson, C.J., "Managing Corporate Environmental Costs and Liabilities," SPE 35761 presented at the International Conference on Health, Safety & Environment, New Orleans, Louisiana, June 9-12, 1996

Of particular interest in this paper is the authors' discussion of the costs of environmental programs and the benefits that are obtained. The authors flatly state, "The concept that corporate environmental spending will increase profits is a myth." However, they do not argue that environmental investments not be made, but note that such investment can improve a company's competitiveness, improve profitability, and reduce potential future liability. "Those companies that embrace principles of habitat protection, recycling, product substitution, (and) pollution prevention will increase market share and profit because they gain a competitive advantage over their peers." So, despite their statement, they make the case that environmental investments are a good business decision. The authors follow with a fairly lengthy discussion of economic benefits of a proactive environmental program. Also, they note the need to assign priorities to environmental projects, which is related to the Environmental Target Setting and Ranking system presented in SPE 35831. Obviously, specific waste minimization investments can be cost

effective (i.e., a good ROR). The authors note that a proactive approach to environmental protection is preferred and waste minimization is a part of that approach.

Gallaher, D.L. and Stene, E.E., "A Customized Area Waste Management Field Manual for E&P Operations," SPE 29715 presented at the SPE/EPA Exploration and Production Environmental Conference, Houston, Texas, March 27-29, 1995

This paper describes the steps Texaco Exploration and Producing Inc. (TEPI) took to produce and develop a waste management field manual that is responsive to the needs of field personnel. TEPI's approach ensured participation by field personnel and their effective use of the manual. The paper provides a fairly comprehensive description of the manual's development and structure. This is a good template for other companies needing such a manual.

Bradford, R.A., "Business Approach to Waste Management," SPE 29703 presented at the SPE/EPA Exploration and Production Environmental Conference, Houston, Texas, March 27-29, 1995

The author, of Phillips Petroleum, argues that environmental management and waste minimization must be part of an overall business plan. He provides a description of a process for establishing environmental performance at the highest level and working it into implementation at the field level. The point that actions, such as waste minimization, require resources and must fit with the company's overall goals is well made.

Emmons, L.N., "Practical Approach to Environmental Protection in the Exploration and Production Industry," SPE 28735 presented at the SPE International Petroleum Conference & Exhibition of Mexico, Vera Cruz, Mexico, October 10-13, 1994

The author is one of several who at this time (1994) published general papers on environmental protection in the E&P industry. The author discusses simple and basic techniques for preventing pollution and minimizing waste. This paper is just another example of the industry's growing awareness of the importance and need for identifying and implementing waste minimization techniques.

Owens, C.K., "Exploration and Production Waste Management Guidelines From the E&P Forum," SPE 27153 presented at the Second International Conference on Health, Safety & Environment in Oil & Gas Exploration and Production, Jakarta, Indonesia, January 25-27, 1994

The author, of Exxon Production Research Co., describes the contents of the E&P Forum's publication "Exploration and Production Waste Management Guidelines" (E&P Forum Report No. 2.58/196 (July 1993)). See the following citation:

E&P Forum, "Exploration and Production Waste Management Guidelines," E&P Forum Report No. 2.58/196 (September 1993)

The home page for the International Association of Oil and Gas Producers (formerly the E&P Forum) is http://www.ogp.org.uk/index.html. The specific URL for accessing and downloading "Exploration and Production Waste Management Guidelines" is: http://www.ogp.org.uk/pubs/196.pdf. "Exploration and Production Waste Management Guidelines" provides an overview of waste generation in oil and gas E&P and waste management options, including waste minimization. The publication provides the framework for developing an area-specific waste management plan (apparently taken from API) and a template for developing a useful waste inventory.

Lettow, J.H., III, "Pollution Prevention at an Arctic Oil Field and Camp," SPE 26029 presented at the Western Regional Meeting, Anchorage, Alaska, May 26-28, 1993

The author describes ARCO Alaska's development of a pollution prevention, or waste minimization, program. Particularly useful is the author's discussion of the structure, organization, and planning for the program. Discussed are the roles of all personnel, management involvement, the importance of "life-cycle" cost analysis, an inventory/tracking system, a new chemical purchase procedure, training, and personnel "buy-in." The paper is a good stimulus for other companies considering a waste minimization planning process. Note that, even though the discussed plan relates to a remote operation (Alaska North Slope), many of the program's elements may be applied anywhere. The author also offers a list of waste minimization achievement examples.

Benoit, J.R., and Schuh, M.G., "Waste Minimization Program at Sour Gas Facilities," SPE 26011 presented at the SPE/EPA Exploration and Production Environmental Conference, San Antonio, Texas, March 7-10, 1993

The authors discuss the development and implementation of a successful waste minimization program. They discuss key elements and benefits. Also, they discuss the waste audit and its use, for example analyzing "material balance" to identify opportunities. A total of 22 significant waste streams were identified at the plant with six being identified as priority wastes. An in-depth review of alternative practices for managing and minimizing the priority wastes was undertaken resulting in an estimated savings of $295,000 annually and a disposal volume reduction in the order of 55,000 lbs. The authors state that a capital expenditure of $395,000 was made to achieve the reductions; therefore, payback was in less than a year and a half. Other benefits were an improved general awareness among plant personnel of wastes associated with various operations, a better understanding of liabilities and costs involved with poor or outdated waste handling and disposal practices, and finally a more optimistic attitude toward waste minimization and management.

Savage, L.L., "Even if You're on the Right Track, You'll Get Run Over if You Just Sit There: Source Reduction and Recycling in the Oil Field," SPE 26009 presented at the SPE/EPA Exploration & Production Environmental Conference, San Antonio, TX, March 7-10, 1993

This paper discusses the change in emphasis from ""end-of-pipe"" waste management to source reduction and recycling. The waste management hierarchy is defined as the following sequence of preference: 1) source reduction, 2) recycling, 3) treatment, and 4) disposal. Each waste management option in the hierarchy is discussed. A brief background of oil and gas waste and changes in environmental regulation is given. The paper concludes with numerous examples of source reduction options and recycling opportunities.

Griffin, J.M., and Marinello, S.A., "Environmental Practices Training for Oilfield Operations Personnel: Course Content and Measurement," SPE 25972 presented at the SPE/EPA Exploration & Production Environmental Conference, San Antonio, Texas, March 7-10 1993

This paper presents a framework for environmental training. Although the author does not emphasize waste minimization, he does offer some good points. The primary point is that company management should, with field employee input, establish expectations for waste reduction and environmental performance and the training plan. Then each operating area's environmental performance should be measured (e.g., waste reduction and cost savings). Other papers provide good information on waste inventory tracking, which would be helpful. The author correctly notes that measurement provides field employees with valuable feedback, which validates waste minimization efforts. Of course, the training also includes sessions to educate employees on the importance of proper waste management and waste minimization. Also included is a discussion of the consequences of regulatory noncompliance and the effect on the company and industry. The authors make a particularly important point: Field employees should be empowered to make changes that will result in waste minimization and improved environmental performance. And, they should be rewarded for success.

Derkics, D.L. and Souders, S.H., "Pollution Prevention and Waste Minimization Opportunities for Exploration and Production Operations," SPE 25934 presented at the SPE/EPA Exploration & Production Environmental Conference, San Antonio, Texas, March 7-10, 1993

The authors, of U.S. EPA, provide an overview of waste minimization possibilities for E&P. They describe several substitute drilling muds and additives which should lower toxicity and improve drilling efficiency. They also cite a papers which demonstrate waste minimization through reserve pit design and solids control using chemically enhanced centrifuges.

Anderson, N.K., and Hall, P.M., "Zero Generator Status," SPE 25933 presented at the SPE/EPA Exploration & Production Environmental Conference, San Antonio, TX, March 7-10, 1993

This paper describes the development of an environmental program by an offshore drilling contractor. The goal of the contractor was to achieve ""zero generator"" status to the greatest extent possible. The major philosophical points considered in the development of the plan are discussed (e.g., "...a clear understanding that it was going to have to be the people working on the rigs who would implement the program and make it work."). Features of the plan presented in the paper include an audit of chemicals used and wastes generated and a waste management/minimization training program for rig personnel.

Haynes, K.G., and Redweik R.J., "Hazardous Waste Elimination and Minimization in Exploration and Production Operations," SPE 24609 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, DC, October 4-7, 1992

This paper covers Shell Offshore's early efforts to promote waste minimization within E&P operations. In an effort to protect the environment and to reduce liabilities associated with hazardous wastes, a waste management program was developed to eliminate and minimize the hazardous wastes generated in exploration and production operations. This involved field visits to operating locations and disposal facilities. The program reviewed the types of hazardous wastes generated by operating locations and exploration activities. Methods to eliminate and/or reduce hazardous waste production were implemented. Training for all personnel associated with waste management was provided. The program also required a knowledge of the regulations that govern solid and hazardous waste disposal. The waste management program resulted in an overall reduction of hazardous wastes by 93% over a six year period.

Derkics, et al, "EPA Initiatives for Improving the Management of Crude Oil and Natural Gas Exploration and Production Wastes," SPE 24551 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, DC, October 4-7, 1992

Pollution prevention and waste minimization have become essential components of exploration and production (E&P) operations. Environmental accountability necessitates including pollution prevention and waste minimization in well planning and engineering, and waste management programs. Viable approaches should include waste minimization guidelines, employee training, and development of innovative technologies in addition to good housekeeping practices and product substitution. This paper presents several initiatives instituted by the Office of Solid Waste (OSW) of the U.S. Environmental Protection Agency (EPA) for improving the management of E&P wastes. Through these initiatives OSW encourages a cooperative effort among industry, regulatory agencies, and other interested parties to develop creative solutions for improving E&P waste management practices."

Brown, C.W., "It's NOT Business as Usual – Anymore," SPE 23456 presented at the SPE Eastern Regional Meeting, Lexington, Kentucky, October 22-25, 1991

The author provides an early signal that waste minimization is becoming a good, and sometimes necessary, business decision. The larger portion of the paper addresses federal environmental statutes and regulations implemented since the early 1970s. However, the author highlights the role of waste minimization and includes in his paper API's "Guiding Principles for Environmentally Responsible Petroleum Operations." The API guidelines include a commitment to reduce overall emissions and waste generation and promotion of these principles and practices by sharing experiences and offering assistance to others.

Page, W.B. and Chilton, D.J., "An Integrated Approach to Waste Minimization," SPE 23365 presented at the First International Conference on Health, Safety, and Environment, The Hague, Netherlands, November 10-14, 1991.

The authors (from Schlumberger and Anadrill) present a service company perspective of waste minimization as a company business objective. They state, "The message that waste minimization is not an environmental program – but a business program with environmental consequences – should be communicated to all personnel." Also, their discussion of product substitution and closed-loop wash water recycling may be useful in certain E&P operations (e.g., a large natural gas pipeline compressor facility that also has a service center for the pipeline operation).

Wojtanowicz, A.K., "Oilfield Environmental Control Technology: A Synopsis," SPE 22815, Journal of Petroleum Technology (February 1993) 166-173

In this paper, the author suggests that the solution to environmental problems in the oilfield is to change attitudes from the produce-consume-dispose (PCD) syndrome to an engineering or environmental control technology (ECT) approach. The author states that "evidence exists that there is considerable pollution control potential in drilling engineering." Several examples are given for drilling and production engineering. Examples of ECT in drilling operations include: in-situ reduction of drilled cuttings; improved mud solids control; mud dewatering and reuse of the liquid phase in the mud system; low toxicity mud additive substitutes; and improved cementing techniques. Examples of ECT in production operations include: in-situ reduction of produced water; improved produced water treatment; and continuous pressure monitoring and external mechanical integrity tests (EMT).

Stilwell, C.T., "Waste Management Plans for Drilling and Production Operations," SPE 20713, Journal of Petroleum Technology (January 1991) 67-71

This paper discusses the development and implementation of area waste management plans for drilling and production operations. Some of the topics covered include: waste management concerns; waste management options; area waste management plan; and waste minimization.

The author concludes that development and implementation of an area waste management plan improves a company's waste management by improving understanding of wastes and waste management requirements and by establishing waste management goals and performance standards.

Arscott, R.L., "New Directions in Environmental Protection in Oil and Gas Operations," SPE 17569, *Journal of Petroleum Technology* (April 1989) 336-342

In an early paper on the subject, the author notes the expansion of environmental regulation since the early 1970's. Of note, he states, "Waste management programs are becoming more common to reduce the generation of waste and to recycle waste products." The author also repeats the waste management hierarchy. The vast majority of technical papers and articles addressing environmental regulation and waste minimization follow this paper.

1.3 INVENTORY AND WASTE DATA MANAGEMENT

Garvey, C.A., and Gray, W.A., "Environmental Self Audits for Upstream Petroleum Operators," SPE 35583 presented at the Gas Technology Conference, Calgary, Alberta, Canada, April 26 – May 1, 1996

The authors present a methodology for conducting a comprehensive environmental audit. As well as assuring regulatory compliance, the audit methodology includes the assessment of waste generation and management. An important part of an audit is a detailed waste inventory, accurate waste classification, and use of the waste management hierarchy. The purpose of the audit is to identify and implement opportunities to reduce waste generation and to reuse/recycle wastes, as well as assure regulatory compliance.

Warner, J.W., "Environmental Data Management System," SPE 26363 presented at the 68th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Houston, Texas, October 3-6, 1993

This paper describes the implementation of Amoco Production Company's (APC) Environmental Data Management System (EDMS). While APC's EDMS is comprehensive (it has modules for air permitting, events, permits) the Waste Module is of interest. The Waste Module has three sub-modules: waste inventory tracking, off-site waste management facilities, and waste testing. Waste tracking is a very thorough inventory system which allows APC to track all waste from "cradle-to-grave." Waste testing data allows APC to establish a baseline of "process knowledge" for wastes. The author notes that the waste inventory "has allowed APC to establish a breakdown of the major waste streams and associated costs to determine where the greatest efforts should be directed to help minimize wastes, control costs, and identify waste technology needs."

1.4 TRAINING

Paul, C.A., "Environmental Training: The Broad View," Proceedings of the 5th International Petroleum Environmental Conference, Albuquerque, NM, October 20-23, 1998

The author provides numerous reasons to conduct environmental training. He lists ten benefits of environmental training. As well as improving the potential for waste minimization, training can result in improved regulatory compliance and cost savings. The paper explains certain training that is required by federal regulations and recommends other training to improve environmental management. The paper provides a good discussion of how training should be developed and implemented. Basic rules are discussed: 1) know the limits of training; cover basic requirements; keep current; keep records; and involve management. This paper provides a very good overview of environmental training basics.

Olszewski, R.E., et al, "A Partnership in Upstream HSE Technology Transfer," SPE 35768 presented at the International Conference on Health, Safety & Environment, New Orleans, Louisiana, June 9-12, 1996

This paper describes the development and implementation of a training program (tailored for Indonesia). The program does not emphasis waste minimization, instead addressing overall environmental aspects. But, the program does offer an example of the importance of training.

Seith, B.J., et al, "Achieving Environmental Awareness: A Comprehensive Training and Awareness Program," SPE 26364 presented at the 68th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Houston, Texas, October 3-6, 1993

The authors describe an educational program developed by BP Exploration (Alaska) to promote a change in behavior and attitude of all employees regarding environmental protection. The program included BP's contractors. A primary focus of the program was pollution prevention and waste minimization. Specific program "modules" addressed waste management and minimization and spill prevention. BP was prompted to implement the program because of increasingly strict environmental regulations and the sensitive Artic environment. But, this paper is a good example of how any company can use training to encourage and realize improved environmental performance, especially through waste minimization and spill prevention.

Also *see* in "General Discussions on Waste Minimization:" Griffin, J.M., and Marinello, S.A., "Environmental Practices Training for Oilfield Operations Personnel: Course Content and Measurement," SPE 25972 presented at the SPE/EPA Exploration & Production Environmental Conference, San Antonio, Texas, March 7-10 1993

SECTION 2

DRILLING AND COMPLETION OPERATIONS

Many opportunities exist for minimizing wastes associated with drilling and completing crude oil and natural gas wells. Numerous effective waste minimization opportunities exist, and the technical papers and articles referenced below discuss many of these opportunities. For example, operators' have recognized the benefits of drilling slim holes and improved solids control. This section provides numerous references which may provide useful information to operators interested in minimizing waste generated by their drilling operations.

This section provides references to technical papers and articles which address the following:

2.1 A General Overview of Waste Minimization in Drilling Operations

2.2 Drilling in Sensitive Environments

2.3 Drilling Fluid Surface System Design

2.4 Drilling Fluid Solids Control and Closed-Loop Systems

2.5 Drilling Fluids - Alternatives

2.6 Other Drilling Systems That Can Minimize Waste

- Drilling With Casing
- Drilling With Coiled Tubing
- Drilling With A Snubbing Unit
- Drilling With Air
- Drilling With Cable Tools

2.7 Drilling and Completing With Expandable Casing

2.8 Drilling "Slim" Holes

2.9 Multilateral Drilling and Completion

2.10 Product Substitution Opportunities at the Drill Site

- Additives for Differential Sticking ("Spotting Fluids")
- Pipe Dope
- Chemicals
- Gas for Underbalanced Drilling

2.11 Recycling Drilling Wastes

Recycling Drilling Mud

Recycling Water at a Drilling Site

2.12 Well Completion

Blast Furnace Slag Mud Converted to Cement as an Alternative

Casing and Tubing

Cementing

Mixing Fracturing Fluids and Cement On-The Fly

Slim Hole Completions

Using Coiled Tubing

Using A Snubbing Unit

2.1 A General Overview of Waste Minimization in Drilling Operations

Several technical papers provide a more comprehensive overview of waste management and environmental performance in drilling operations. The authors of these papers touch on many of the environmental and waste minimization aspects described more specifically in the various topics under "Drilling and Completion Operations."

Veil, J.A., "Drilling Waste Management: Past, Present, and Future," SPE 77388 presented at the SPE Annual Technical Conference and Exhibition, San Antonio, TX, September 29-October 2, 2002

The author provides an overview of drilling waste management practices for both onshore and offshore operations. The author notes particular interest in waste management approaches based on waste minimization. Although the paper does not provide detail regarding waste minimization techniques, it does briefly discuss currently effective techniques such as use of synthetic drilling fluids, drilling with coiled tubing, and recycling drilling mud. The author notes that future waste minimization opportunities include newer environmentally-friendly drilling fluids, an alternative to barite as a mud weighting agent, and more efficient thermal treatment of oil-based cuttings to recycle oil. Of interest, the author indicates that he and two major oil and gas companies have been funded by the U.S. Department of Energy to develop an interactive web-based information system to provide up-to-date technical, economic, and regulatory information on drilling waste management. This web site, if implemented, may offer a good source of drilling waste minimization information.

Greaves, C, et al, "Field Application of 'Total Fluids Management' of Drilling Fluids and Associated Wastes," SPE 66552 presented at the SPE/EPA Exploration and Production Environmental Conference, San Antonio, TX, February 26-28, 2001

The authors provide an excellent description of British Petroleum's implementation of a "Total Fluids Management" (TFM) process in an 11-rig drilling operation in Columbia. TFM, also referred to as integrated fluids management, is the holistic management of drilling fluids, solids control, waste processing, waste management, and associated activities. The authors present a detailed description of the TFM process, including the planning process, total cost accounting, implementation, measuring success, and transferring lessons learned for continuous improvement. The paper cites several critical elements of TFM; such as personnel training, goal setting, and contracting. The TFM project was very successful with respect to waste minimization (e.g., increased recycling of oil-based fluids). The authors state that TFM reduced the combined costs of fluids, waste management, and related services by an average of $753,000 per well in 1999 compared to the pre-TFM 1997 benchmark.

Mehra, S. and Abedrabbo, A., "Light Modular Rig for Minimal Environmental Impact," SPE 36045 presented at the International Conference on Health, Safety, and Environment, New Orleans, LA, June 9-12, 1996

This paper addresses the overall design and operation of a drilling rig to reduce environmental impact. The authors address several issues presented in this chapters references. The authors (of Schlumberger Sedco Forex) describe the design and implementation of a light modular drilling rig and operational methodologies to minimize environmental impact and waste generation. The authors do not cite exact cost savings or implications, but indicate money is saved (overall, not just due to waste minimization). The authors describe how the new modular rig and methodologies minimize rig footprint, reduce waste generation, reduce rig water use, and enhance recycling. Examples of waste minimization efforts include: drilling slim holes when feasible to reduce cuttings; using comprehensive solids control and tanks with cylindrical shape and spherical bottoms (to reduce dead volume) to reduce drilling mud volumes; and channeling fluids to a main collection tank for treatment and recycling.

Clementsen, S., and Berntsen, M., "How to Promote and Integrate Quality, Health, Safety and Environmental Concerns in Use of Different Drilling Fluid Systems," SPE 35853 presented at International Conference on Health, Safety & Environment, New Orleans, LA, June 9-12, 1996

The authors' focus is on the health and safety of the drilling rig crew (in this case on an offshore drilling rig). However, the authors include suggested procedures that also minimize environmental impact. The authors provide checklists which include inspections/actions which will help prevent accidental spills/releases. This is important in any drilling operation, on land or at sea. Of particular note, the authors discuss the importance of all disciplines (e.g., mud engineers, drilling supervisors, EH&S staff) in the drilling project working together ("interdisciplinary cooperation") to ensure improved quality, health, safety and environmental

performance. They also build on past experiences. This is effected by using the "Integrated Guideline for the Use of Various Types of Drilling Fluids" (developed by Odfjell Drilling, Baker Hughes INTEQ, and Kokstad Occupational Health Centre). Although this paper is from the perspective of EH&S persons in Europe, it is a useful resource for people involved in planning a drilling operation anywhere.

Cline, J.T., and Piper, W.A., "Drilling Waste Controls," SPE 27162 presented at the Second International Conference on Health, Safety & Environment in Oil & Gas Exploration & Production, Jakarta, Indonesia, January 25-27, 1994

The authors discuss Amoco Production Company's efforts to identify and implement advanced waste control technologies. In particular, the authors briefly describe their "Environmental Data Management System" (EDMS) for improving environmental performance. The EDMS is essentially a "cradle-to-grave" waste generation, analysis, and tracking system. The EDMS helps to focus on technological needs and helps to identify cost benefits of waste minimization. The authors also provide case histories, which include an example of successful, cost-effective, improved solids control to reduce drilling waste generation.

Ballantine, W.T., "Drillsite Cost Savings Through Waste Management," SPE 26387 presented at the 68th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Houston, Texas, October 3-6, 1993

The author, with Newpark Resources Inc., discusses today's litigious atmosphere and the best ways to limit liability by minimizing waste at a drill site. The author suggests techniques through which environmentally managed operations can reduce and limit an operator's cost exposure related to waste clean-up and ultimately the operator's liability. Most suggested techniques do not constitute waste minimization, but there are a few good examples. Also, the author addresses waste segregation, which may minimize waste. Some of the author's waste minimization suggestions include: multiple pit systems to segregate waste; automatic shut-off nozzles on all hoses; and recycle reserve pit water and ring levee water.

Longwell, H.J., and Akers, T.J., "Economic Environmental Management of Drilling Operations," SPE 23916 presented at the 1992 IADC/SPE Drilling Conference, New Orleans, LA, February 18-21, 1992

This paper presents environmental and regulatory initiatives developed by Exxon's New Orleans Drilling Organization. Specifically covered are drilling waste minimization techniques and disposal options, recycling of drilling waste streams, and environmentally managed drilling location design. The author claims that some of these initiatives have resulted in a fifty percent reduction in drilling location waste management costs at Exxon's Chalkley Field. Closed-loop mud systems and chemically enhanced centrifugation are the waste management methods discussed.

Thurber, N., "Waste Minimization for Land-Based Drilling Operations," SPE 23375, Journal of Petroleum Technology (May 1992) 542-547

In one of the early papers recognizing the increased attention to industry environmental performance, the author discusses methods for minimizing wastes from onshore drilling operations. Suggested waste minimization methods include the use of closed loop drilling fluid systems, cuttings dewatering systems, rig water reuse, and substitution of less toxic mud additives. The paper includes tables which list generic mud additives and possible substitutes, and the common sources and volumes of water discharge to reserve pits. Charts are also presented showing solids removal economic analyses, hydroclone performance, and centrifuge performance. The author concludes that implementation of these waste minimization techniques can result in improved environmental performance and reduced well costs.

Geehan, T., et al, "Control of Chemical Usage in Drilling Fluid Formulations To Minimize Discharge to the Environment," SPE 23374 presented at the First International Conference on Health,, Safety and Environment, The Hague, The Netherlands, November 10-14, 1991

This paper presents the evaluation and results of a study comparing the concurrent operations of two adjacent drilling rigs (offshore Dubai, UAE). One rig used traditional drilling fluid formulations and monitoring, while the second rig used a systematic approach in the management of drilling fluids and solids control. The comparison was based on factors such as chemical to cuttings ratio and mud to cuttings ratio. A detailed analysis of such factors for each rig's operations is presented. The results of the project showed that the systematic approach achieved a 29% reduction in total chemical discharge and a 24% reduction in drilling fluid cost, as well as improved operating efficiency. In addition, a comparison to wells drilled on a third platform in the vicinity showed a 58% reduction in the total chemical discharge. Further refinements planned include using a slim hole casing design where possible to reduce the required mud volume. The systematic approach is also described as an integrated drilling fluids management approach. This means that the mud surface system and the mud (e.g., in the hole) are treated as integral parts of one whole process. Frequent monitoring of the entire system is essential. This includes using mass balance techniques to measure the efficiency of solids control equipment. This case history is an excellent example of source reduction efforts resulting in more efficient operations and reduced operating cost.

Alford, J.T., "Zero Discharge Design Considerations for Jackup Drilling Rigs," SPE 23363 presented at the First International Conference on Health,, Safety and Environment, The Hague, The Netherlands, November 10-14, 1991

This paper describes a zero discharge design intended to make jackup drilling rigs as environmentally clean as possible. Research of waste streams, traditional methods of collection and treatment, rules and regulations, and various types of treatment equipment was conducted. The information gathered by this research was used to develop a design for use in upgrading existing rigs and to also provide a system to be incorporated in new rig building programs. These modifications are intended to lead to increased catchment of effluent streams, selection of

latest technology treatment equipment and increased use of monitors. The author states that the project has resulted in the design of systems that will make both new and existing jackup rigs more environmentally acceptable. Although this paper is directed to jackup rigs used for offshore drilling, several of the waste minimization options discussed could be considered for onshore application.

2.2 DRILLING IN SENSITIVE ENVIRONMENTS

Kudia, M.S. and McDole, B.W., "Managing Drilling Operations in a Sensitive Wetlands Environment," SPE 35780 presented at the International Conference on Health, Safety & Environment, New Orleans, LA June 9-12, 1996

The authors discuss the drilling plan established for a sensitive wetlands environment in a national wildlife refuge. Though most plan components (beyond those of a typical drilling plan) were necessary to obtain USFWS permission to drill, the company implemented several waste minimization techniques that are effective in any operation.

The drilling project used a closed-loop drilling fluid system (which reduced waste drilling fluid quantity), used bulk drilling mud and additives systems (which eliminated bag/container waste), installed secondary and tertiary spill containment systems, and used less toxic substitute materials (e.g., biodegradable hydraulic oil, non-toxic pipe dope, and less toxic lubricants). Also, certain wastes were used as daily cover at a municipal landfill. Custom made drip pans (which reduced soil contamination) were reused on subsequent drilling projects. Because they did not account for the monies saved by reducing waste volumes/disposal costs or by eliminating spill clean-up costs, the final economics of the project are not clear.

Smith, R., "Environmental issues and Solutions for Exploratory Drilling in Sensitive Areas," SPE 29704 presented at the SPE/EPA Exploration & Production Environmental Conference, Houston, Texas, March 27-29, 1995

The author discusses an exploratory drilling project conducted near the Grand Teton National Park in an environmentally sensitive area. From an environmental perspective the primary objective of the project was to successfully drill the exploratory well with minimal impact and without incident. Detailed pre-planning accounted for all facets of the operation. One of the first things that was done was to institute a comprehensive training program for every person who would go on site. The operator recognized that waste minimization was a necessary component of the plan. Some of the waste minimization techniques used were: a semi-closed loop solids removal system to minimize mud volume; a much smaller, lined reserve pit; and recycling all recyclable waste. The entire drilling area was sloped and enclosed in drain canals, drainage ditches and berms, terminating in a lined 70-foot by 125-foot runoff containment pit. The runoff in the pit was available for use as drilling fluid makeup water. Finally, the fuel storage area was contained using a berm and impermeable liner. Although the measures taken in this project were in response to strict federal controls (e.g. BLM), much of the plan offers good ideas for reducing waste generation and environmental impact of any drilling project.

2.3. DRILLING FLUID SURFACE SYSTEM DESIGN

Also *see* IADC/SPE 23916 in Section 2 under "Drilling Fluid Solids Control and Closed-Loop Systems."

Rautela, M.S., "Prevention of Wet Pull Out or Splashing," SPE 23834, Society of Petroleum Engineers unsolicited paper, September 27, 1991

This unsolicited paper briefly presents a method to prevent the loss of drilling mud from drill pipe as it is pulled out of the hole. The author states that the displacement of the drilling mud by drilling mud of the same weight, but with significantly lower gel strength, will overcome this problem. A detailed description of the application of this method, including specific drilling mud properties, is presented. This method may reduce mud losses and reduce the quantity of required rig wash.

Wisnie, A.P., and Brazzel, R., "Design and Implementation of a Bulk Mud Additive System To Reduce Personnel Exposure and Eliminate Waste," IADC/SPE 23883 presented at the 1992 IADC/SPE Drilling Conference, New Orleans, Louisiana, February 18-21, 1992

In an effort to limit personnel exposure to oilfield chemicals and simultaneously reduce additive packaging and shipping waste, a bulk additive system was designed and installed for handling drilling mud products on a drilling project. Although some problems were initially encountered, the system was modified to completely fulfill its objectives. Both occupational safety risks and concerns for environmental contamination from wastes were significantly reduced. Efforts are being made to improve the system for future drilling projects. This project eliminated several thousand pounds of unnecessary packaging materials. The authors briefly discuss the economics of the project. Cost savings due to reduced packaging and shipping materials (e.g., shrink wrap and pallets), reduced spillage loss, and reduced waste disposal more than paid for the expense of increased mud costs (per agreement with the drilling contractor) and rig modifications. The operator's net savings was $3,500. The authors note that savings should greatly improve for future drilling projects, because a large portion of the rig modification costs are one-time.

Barragan, et al, "SIC-System for Identifying Contaminants in Drilling Fluids," SPE 23625 presented at the Second Latin American Petroleum Engineering Conference, II LAPEC, of the Society of Petroleum Engineers, Caracas, Venezuela, March 8-11, 1992

This paper presents software which identifies various contaminants from the analysis of their properties during drilling operations. A TURBO PASCAL program was developed using some artificial intelligence techniques. The program, named SIC (System for Identifying Contaminants), verifies for each usual contaminant, the possibility of its degree of influence on each drilling fluid property. Changes in drilling fluid properties, determined by regular testing at specified intervals, will indicate the type and degree of contamination and the required treatment. Monitoring drilling fluid properties can help with efficient use/addition of drilling mud additives and reduce the final volume of waste drilling fluid.

Minton, R.C.; and Bailey; M.G., "An Assessment of Surface Mud Systems Design Options for Minimizing the Health, Safety and Environmental Impact Concerns with Drilling Fluids," SPE 23362 presented at the First International Conference on Health, Safety and Environment, The Hague, The Netherlands, November 10-14, 1991

The authors, of BP Exploration Operations Co. Ltd. and Thule Rigtech Corp., proposed a drilling fluid surface system design concept that resolves the environmental, occupational hygiene, and safety issues associated with conventional additive mixing. Automation of the chemical handling and a dosing system are the central elements of the concept. According to the authors, such a design permits a significant reduction in the surface volume requirements (i.e., reduced mud volumes). Other benefits of the system include improved inventory control, easier mixing, and reduced additive waste (e.g., spills during handling). The authors project cost savings, but in this application, savings are with respect to offshore rig requirements (e.g., reduced space and weight requirements). However, automated additive container handling and additive dosing systems should be considered in land drilling. Presuming improved and less costly systems are now available, a land drilling operation may achieve a cost benefit due to reduced drilling waste generation and improved drilling mud system efficiency.

Hall, C.R., et al, "The Use of a Managed Reserve Pit System to Minimize Environmental Costs in the Pearsall Field," SPE 22882 presented at the 66th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Dallas, TX, October 6-9, 1991

The authors discuss the use of a managed reserve pit system for reducing drilling waste disposal costs, site remediation costs, and long-term environmental liability. The managed reserve pit system employs waste segregation by building a series of small pits which each hold a specific waste rather than building one large pit. In this manner exempt and non-hazardous wastes can be segregated from non-exempt and hazardous wastes. The authors report significant savings on disposal and site remediation costs. The system also improves the ability to recycle certain wastes.

2.4. DRILLING FLUID SOLIDS CONTROL AND CLOSED-LOOP SYSTEMS

Improved solids control and closed-loop fluid systems have been shown to effectively reduce drilling waste generation. In planning any drilling operation, these elements should be considered and implemented if economically feasible. Solids control allows more efficient use and recycling of drilling fluids. A closed-loop system reduces the need for drilling pits, minimizes the potential for pollution, and enhances the ability to recycle drilling fluid. One important aspect of solids control is the need for system operators who are well-trained in the use and operation of solids control systems. The following selected technical papers and articles provide a good overview of solids control and closed-loop fluid systems.

Astrella, L. "Total Fluids Control to Reduce Operating Cost and Environmental Impact," Proceedings of the 6th International Petroleum Environmental Conference, Houston, TX, November 16-18, 1999

This paper emphasizes the economic and environmental benefits of drilling using a closed-loop fluid system in conjunction with automated fluids control equipment. The author argues that such a fluid system results in reduced drilling costs and significant waste minimization. He provides a cursory process (and an example) for comparing the cost of drilling with the closed-loop system and a conventional reserve pit system. The author notes that, in general, the closed-loop system is most cost effective when used for drilling programs of short duration, where water is not readily available or where regulations require off-site disposal of drilling fluids. According to the author, waste minimization benefits include: up to an 80% reduction of waste product removal and disposal; reduced chemical handling and use; and reduced surface impact. The drill site will occupy a smaller footprint and hauling of water and mud additives is greatly reduced. Also, according to the author, operational benefits of the automated fluids control include improved rate of penetration. This paper may be useful to an operator contemplating closed-loop drilling.

This paper is available at http://ipec.utulsa.edu/.

A.J. Robb III, A.J. and Beaty, T.D., "Waste Management and Minimization in the Hugoton Field, Southwest Kansas," SPE 35914 presented at the International Conference on Health, Safety & Environment, New Orleans, Louisiana, June 9-12, 1996

The authors describe Mobil E&P's use of a solids control system in an infill drilling program consisting of relatively shallow (about 2,800 feet) wells. Prior to implementing a solids control system, the operator used conventional shakers to remove solids. The desired drilling fluid properties were maintained by addition of water and additives. To reduce the quantity of drilling waste, Mobil E&P implemented a solids control system consisting of a chemically-enhanced, semi-closed loop centrifuge system. The authors provide a detailed description of the system and its operation. The system resulted in an 80% reduction in drilling waste volume and a savings of $858/well ($307,000 for the 358 well in-fill drilling program). Along with the savings is the goodwill and improved relations with the regulators and land owners. The authors emphasize that this effort was part of a structured waste management system which included a waste minimization initiative. The system is validated by tracking waste volumes and costs. Importantly, Mobil E&P worked closely with the drilling contractors and mud companies to successfully implement the system.

Astrella, L., and Wiemers, R.A., "Evaluating Closed Loop Systems," IADC/SPE 35116 presented at the 1996 IADC/SPE Drilling Conference, New Orleans, Louisiana, March 12-15, 1996

The authors offer a methodology for determining whether it is cost-effective to use a closed-loop system for water-based mud. The closed loop drilling fluid system allows "pitless" drilling, which offers certain advantages. The authors' methodology addresses closed loop system costs such as surface damages, solids removal, water, mud, ancillary equipment, flocculation units, labor, and chemicals. Those costs are compared to the cost associated with conventional earthen pits, such as surface damages, construction and closure. The authors state that "modern closed-loop systems are becoming more dependable and efficient," and that "(d)rilling pitless is becoming an economically attractive alternative in many drilling programs." They also discuss intangible benefits of closed loop systems, such as improving the company's environmental performance and public image.

Thompson, L.F., "Drilling Fluids Waste Minimization and Stabilization Using Polymer Technology," SPE 29196 presented at the 1994 Eastern Regional Conference and Exhibition, Charleston, West Virginia, November 8-10, 1994

The author discusses the use of polymers to dewater drilling mud in a reserve pit prior to closure. The author also indicates that polymers may be used in lieu of centrifugal filtering for solids control during drilling. At the very least, water from flocculated mud in the reserve pit can be recycled as drilling fluid make-up water.

Wojtanowicz, A.K., "'Dry' Drilling Location - An Ultimate Source Reduction Challenge: Theory, Design, and Economics," SPE 26013 presented at the SPE/EPA Exploration & Production Environmental Conference, San Antonio, Texas, March 7-10, 1993

The author presents an iterative program (written in FORTRAN 77) that analyzes a proposed drilling mud program as an integrated system. The purpose of such an analysis is to allow the selection of proposed drilling projects that can economically be conducted as "dry" wellsites. A "dry" wellsite denotes a drilling operation without the use of an earthen reserve mud pit in land drilling, or without the overboard dumping of bulk drilling fluid in offshore drilling. The author presents mechanistic and economic models of the controlled-volume drilling process and their theoretical use to design a "dry" location. The program is capable of predicting optimum mud system equipment performance, waste volumes, and costs. A significant conclusion of the study is that minimal drilling waste is generated at an optimum efficiency of solids removal, not at the maximum removal efficiency. (Note: The author states that he developed the concept, theory, and methodology while a 1991/1992 Conoco Environmental Research Fellow at Conoco, Inc. The paper does not indicate commercial availability of the described computer program.)

Longwell III, H.J., and Akers, T.J., "Economic Environmental Management of Drilling Operations," IADC/SPE 23916 presented at the 1992 IADC/SPE Drilling Conference, New Orleans, Louisiana, February 18-21,1992

This paper presents environmental and regulatory initiatives developed by Exxon's New Orleans Drilling Organization. As in other instances, the improvements in waste management and waste minimization were spurred by increasingly strict environmental regulatory requirements (e.g., drill site closure standards.). The authors focus on the use of closed-loop drilling fluid systems with chemically enhanced centrifuges. The authors present the costs of drilling several wells, some using conventional reserve pits and others using closed-loop systems and various degrees of solids control. The general result was that the closed-loop systems proved to reduce overall drilling costs at both onshore and barge locations. The authors state that some of these initiatives resulted in a fifty percent reduction in drilling location waste management costs at Exxon's Chalkley Field. The authors describe other waste minimization techniques including segmented pit systems, stormwater drainage and collection systems for the rig area for recycling and use in the drilling fluid system, and a bulk drilling mud additive handling system

Bouse, E.E., and Carrasquero, J.E., "Drilling Mud Solids Control and Waste Management," SPE 23660 presented at the Second Latin America Petroleum Engineering Conference, II LAPEC, of the Society of Petroleum Engineers, Caracas, Venezuela, March 8-11, 1992

The authors review the importance of solids control and its relevance to waste management and discuss closed-loop mud systems and other methods of handling drilling fluid waste. The paper addresses in some detail the proper design, installation, and monitoring of the solids removal system. The authors describe the optimum closed-loop system and its components, including sand traps, degassers, desanders, and centrifuges. The authors also explain common pitfalls in solids control (e.g., using only two-stage centrifuging) which lead to degraded mud quality. This paper is an excellent reference for improving solids control to reduce drilling waste quantity.

Tapin, T.P., and Blake, L.D., "Dewatering Technology: A Current Overview and SE Asia Applications," SPE 23034 presented at the ASIA-Pacific Conference of the Society of Petroleum Engineers, Perth, Australia, November 4-7, 1991

The authors provide a good discussion of the basics of drilling mud solids control and dewatering using chemically enhanced centrifuges. The authors explain certain pitfalls in solids control and precautions that must be taken. For example, the authors suggest recycling clarified water for reuse in the drilling mud and note that the chemical flocculant must first be neutralized. The authors note that rig site dewatering combined with recycling may result in: 1) reduced waste volumes; 2) reduced disposal costs; 3) reduced potential liability; and 4) a cleaner drill site. Also, the removal of fine solids (5 microns and less) through dewatering can improve penetration rate and hole condition, which saves time and money. The authors note that in some

instances, attempts at solids control with excessive centrifuging can actually increase the proportion of fine solids in the mud.

Halliday, W.S., et al, "Closed-Loop Operations Using Alternate Dewatering Technology," SPE 20461 presented at the 65th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, New Orleans, Louisiana, September 23-26, 1990

This is an excellent reference for operators considering closed-loop drilling fluid systems. The authors discuss optimization of solids control equipment for waste minimization, as well as for managing mud rheology. The authors discuss closed-loop systems using dewatering equipment that can eliminate the need for reserve pits. The authors also provide a fairly detailed overview of an economic feasibility analysis to determine whether or not a closed-loop system with dewatering would be cost-effective. A description of equipment (including dewatering device alternatives), monitoring, layout, and daily cost monitoring is given as well as case histories for inland marine wells in Louisiana. Charts at the end of the paper present statistics on mud properties at various stages of drilling operations and the economics for a well using a dewatering system versus the estimated cost had a dewatering system not been used. The authors estimate that the dewatering system used on one well saved nearly $107,000 - primarily in reduced location and waste disposal costs.

Sanders, J.M., "Minimized Hauloff While Drilling in a Zero Discharge Area," SPE 19529 presented at the 64th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, San Antonio, Texas, October 8-11, 1989

This paper describes solids control and water recycling while drilling a 23,500 foot offshore well. Large waste quantities were expected because a 17 ½ inch hole was to be drilled to a depth of 16,500 feet. Because all waste had to be collected and brought ashore, the economics of this project were excellent, however, are not directly applicable to onshore drilling where disposal costs are less. The author provides a useful description of improved solids control and rig water recycling techniques (e.g., gray water) which may be applicable in any area.

Malachosky, E., et al, "Impact of Dewatering Technology on the Cost of Drilling-Waste Disposal," SPE 16098, *Journal of Petroleum Engineering* (June 1991) 730-736

The authors describe Arco's use of a mobile, chemically enhanced centrifugation dewatering system on two deep wells in California. The project, conducted in 1989, evaluated the cost-effectiveness of the system at well sites where operational considerations limited the size of the reserve pit and drilling waste disposal was required. The project was considered a success because the cost to operate the dewatering unit was less than the cost to dispose of a comparable volume of drilling waste at an appropriate disposal site. The drilling waste volume and make-up water volume were significantly decreased. The authors provide a detailed description of the systems design and operation and an analysis of operating parameters. (Note: This paper was

presented at the 64th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, San Antonio, Texas, October 8-11, 1989.)

Lal, M., "Economic and Performance Analysis Models for Solids Control," SPE 18037 presented at the 63rd Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Houston, Texas, October 2-5, 1988

The author provides a very detailed discussion of solids control modeling to develop an analytical basis for the economic analysis and selection of proper solids control equipment. The author provides a very structured discussion of the drilling fluid system and the effects of solids control. The result was a computer-based modeling program which could provide an analysis of the economic feasibility of using solids control. The modeling program was successfully applied to an infill drilling program. The author discusses the field application in detail. The field application demonstrated the functionality of the model and achieved the predicted performance and cost savings. It should be noted that the field application was subject to restrictions (e.g., minimal pit construction and extra mud and wastes had to hauled off-site for disposal). As noted by the author, The economics and selection of solids control depends on "several factors such as drilling conditions, environmental regulations, dilution and disposal costs…" This paper is an excellent resource for an operator interested in the economic analysis of solids control for closed-loop drilling.

Wojtanowicz, A.K., "Modern Solids Control: A Centrifuge Dewatering-Process Study," SPE 16098, *SPE Drilling Engineering* (September 1988) 315-324

The author presents the results of a study to investigate the feasibility and technical aspects of the modern solids-control system. The objectives of the study were to establish fundamental principles of drilling mud dewatering, operational variables affecting dewatering performance, and the feasibility of chemical treatment in dewatering. The author notes that effective solids control, including dewatering, can reduce drilling waste volumes. This paper is quite thorough and compliments other technical papers on the subject. This paper is a good reference for operators wishing to gain a greater understanding of solids control.

2.5. DRILLING FLUIDS - ALTERNATIVES

McDonald, W.J., et al, "New Lightweight Fluids for Underbalanced Drilling," Proceedings of the 1999 Oil and Gas Conference, U.S. Department of Energy National Energy Technology Laboratory, Dallas, TX, June 28-30, 1999 (Note: This paper is available at www.netl.doe.gov/publications/proceedings/99/99oil&gas/99o&g.html.)

The authors discuss a U.S. Department of Energy-sponsored project to demonstrate the potential use of hollow glass spheres as a drilling fluid additive. It is argued that the use of the spheres in underbalanced drilling can overcome problems encountered with current air/mist/foam drilling systems. The authors provide a thorough discussion of sphere use and include the results of a

successful field test in California. The spheres were shown to be easily mixed into the mud and to provide the rheological properties of the conventional lightweight muds. With respect to waste minimization, the authors state that the spheres are easily recovered from mud and reused, which reduces costs.

Friedheim, J.E., and Patel, A., "Technical Solutions for Environmental Problems: Novel Drilling Formulations to Minimize Environmental Impact," SPE 52741 presented at the 1999 SPE/EPA Exploration and Production Environmental Conference, Austin, TX, February 28-March 3, 1999

This paper discusses optimization of existing SBM technologies (e.g., optimizing thermal properties to improve recycling) and new (circa 1999) synthetic drilling fluid formulations. One new formulation uses a reversible emulsifier. Reversing an invert emulsion to a water-base allows cuttings to become water wet, which enhances removal of the SBM (synthetic-based mud) on the cuttings (beneficial offshore in that organic loading on the seafloor is reduced). The authors also discuss new glycol-based SBMs, which are water soluble at low temperatures. This eliminates sheen on water. The authors provide a thorough discussion of each formulation, including benefits and limitations. Although SBMs have primarily been used offshore to meet effluent discharge guidelines, the authors note that the technology may become more attractive onshore.

Hanna, I.S., and Abukhamsin, S.A., "Landfills and Recycling Provide Alternatives for OBM Disposal," *Oil and Gas Journal* (June 8, 1998) 118-120

Hanna, I.S., and Abukhamsin, S.A., "Plant Design Allows Drillers to Reuse and Recycle OBM," *Oil and Gas Journal* (June 15, 1998) 71-75

This article was published in two parts. The authors discuss Saudi Aramco's response to the imposition of strict environmental regulation on their practice of discharging oil-based drilling mud (OBM) and oil-wet cuttings to the marine environment. The authors begin with a general discussion of changes made at offshore rigs to improve solids control and collect and manage drilling waste. However, of primary interest is their description of Saudi Aramco's design and construction of an onshore OBM recycling plant. The authors provide a detailed description of the facility, including the physical layout, required operating personnel, requisite equipment for OBM recovery and reconditioning, and required storage facilities. The authors do not provide specific regarding the economic justification. However, they state, "The alternative of disposing used mud by landfarming is uneconomical compared to recycling." Although this example of cost-effective OBM recycling is from the Middle East, it may be duplicated elsewhere. Ideally, less-toxic drilling muds should be substituted for OBM. But, if OBM is necessary and the scope of drilling is sufficient, the feasibility of recycling OBM should be investigated. Also, this two-part article may be of interest to commercial operators considering OBM recycling.

Estes, J., et al, "Bingham Plastic Fluids More Effectively Clean Horizontal Holes," *Oil and Gas Journal* (November 11, 1996) 89-93

The authors provide a detailed explanation of drilling fluid rheological properties. They define Bingham plastic fluids and explain the advantages of Bingham plastic fluid rheological characteristics. Bingham plastic fluids clean horizontal bore holes more effectively than many bentonite or oil base fluids. Basically, Bingham plastic fluids provide slug flow which enhances cuttings transport while minimizing formation damage. The authors state that Bingham plastic fluids are environmentally benign, which provides a good waste minimization option for oil-based fluids. The authors justify the use of a water base mud by giving cost savings based on reduced drilling time costs versus oil base mud cost.

Argillier, J.F., et al, "Development of a New Non-Polluting Ester Based Lubricant for Water Based Muds: Laboratory and Field Test Results," SPE 36862 presented at the 1996 SPE European Petroleum Conference, Milan, Italy, October 22-24, 1996

The authors (Fina Research S.A. and Institut Francais Du Petrole) describe the development and testing of an ester-based drilling fluid additive for improving lubrication. The new additive is "completely biodegradable and non ecotoxic." The additive is designed for use in water-based systems. According to the authors, laboratory and field testing demonstrate that the additive significantly reduces drill stem torque, bit balling and differential sticking. Additionally, the additive is compatible with water-based drilling fluids (e.g., no effect on rheology, can improve filtrate loss reduction, and is readily dispersible). The authors do not discuss the costs or cost savings associated with the ester-based additive, but drilling costs should be expected to be reduced because drilling efficiency is improved. Also not addressed by the authors is the use of the additive in spotting fluids for freeing stuck pipe, though it appears the additive may be useful for this application. *See* also SPE papers 35330 and 28308.

Bland, R., et al, "Low Salinity Polyglycol Water-Based Drilling Fluids as Alternatives to Oil-Based Muds," IADC/SPE 36400 presented at the 1996 IADC/SPE Asia Pacific Drilling Technology Conference, Kuala Lumpur, September 9-11, 1996

The authors describe the development and field application of a high performance, polyglycol water-based drilling fluid. The new drilling fluid was designed to substitute for oil-based and KCl-based drilling fluids. The authors state, "High performance water based drilling fluids are an attractive alternate to oil-based fluids due to the characteristics of the aqueous phase, it's conductivity and typically lower concentration of organics." The authors provide a thorough discussion of the physical properties of polyglycols (chameleonic or thermally activated mud emulsion polyglycols) and the mechanisms by which they stabilize shale. Also provided is a discussion of the results from drilling several wells in Southeast Asia using the polyglycol, water-based mud (including mud formulations). According to the authors, the high performance, polyglycol water based drilling fluid reduced drilling time and dilution requirements, therefore saving drilling costs (even though the fluid cost more). As well, the operator gained environmental regulatory benefits, such as reduced treatment and disposal requirements.

Getliff, J.M., and James, S.G., "The Replacement of Alkyl-Phenol Ethoxylates to Improve the Environmental Acceptability of Drilling Fluid Additives," SPE 35982 presented at the International Conference on Health, Safety & Environment, New Orleans, LA, June 9-12, 1996

The authors note that APEO (alkyl-phenol ethoxylate) is an undesirable drilling fluid additive (and detergent) because of its oestrogenic properties. AOEP biodegrades to persistent compounds (lipophilic metabolites, such as alkyphenols) which are toxic to aquatic life. In E&P, APEO is used in lubricants (oil-based mud, spotting fluid for stuck pipe, etc), and in detergents used for washing rig floors and other equipment used in oil-based drilling. The authors describe tests which indicate that linear alcohol ethoxylates (LAEOs) are suitable alternative (i.e., product substitution) to APEO. LAEO is much less toxic in that it biodegrades to CO2 and water. Further, the authors believe the tests to show that LAEO exceeds the performance of APEO as a drilling mud additive and cleaner.

Hemphill, T., "Prediction of Rheological Behavior of Ester-Based Drilling Fluids Under Downhole Conditions," SPE 35330 presented at the 1996 SPE International Petroleum Conference and Exhibition of Mexico, Villahermosa, Tabasco, March 5-7, 1996

The author, of Baroid Drilling Fluids, describes the construction of "a predictive downhole rheological model of the ester-based drilling fluid…" The model may be used to predict fluid rheological behavior at downhole conditions, evaluate hole cleaning while drilling extended-reach wells, and to pre-well simulate fluid hydraulics and hole cleaning. *See* also SPE papers 36862 and 28308.

Zevallos, M.A.L., et al, "Synthetic-Based Fluids Enhance Environmental and Drilling Performance," SPE 35329 presented at the SPE International Petroleum Conference & Exhibition of Mexico, Villahermosa, Tabasco, Mexico, March 5-7, 1996

The authors discuss the advantages of synthetic-based drilling mud over the traditional oil-based muds and water-based muds. SBM provides a product substitution opportunity in that SBM is less toxic than OBM. However, SBM still poses more environmental risk than water-based muds (WBM), which should be considered. The authors cite numerous SPE technical papers on the development, use, and toxicity of SBM. Also, see the following selected SPE papers:

> Friedheim, J.E., and Pantermuehl, R.M., "Superior Performance With Minimal Environmental Impact: A Novel Nonaqueous Drilling Fluid," SPE/IADC 25753 presented at the 1993 SPE/IADC Drilling Conference, Amsterdam, February 23-25, 1993
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> Park, S., et al, "The Success of Synthetic-Based Drilling Fluids Offshore Gulf of Mexico: A Field Comparison to Conventional Systems," SPE 26354 presented at the 68th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Houston, TX, October 3-6, 1993

Carlson, T., and Hemphill, T., "Meeting the Challenges of Deepwater Gulf of Mexico Drilling With Non-Petroleum Ester-Based Drilling Fluids," SPE 28739 presented at the SPE International Petroleum +Conference & Exhibition of Mexico, Vera Cruz, Mexico, October 10-13, 1994

McKee, J.D.A., et al, "A New Development Towards Improved Synthetic Based Mud," SPE 29405 presented t the 1995 SPE/IADC Drilling Conference, Amsterdam, February 28 – March 2, 1995

Burke, C.J., and Veil, J.A., "Synthetic Drilling Muds: Environmental Gain Deserves Regulatory Confirmation," SPE 29737 presented at the SPE/EPA Exploration & Production Environmental Conference, Houston, TX, March 27-29, 1995

The authors describe the SBM systems developed (as of 1995) as substitutes for conventional drilling muds (WBM & OBM). The purpose of the paper, however, is to make the case for revision of EPA effluent discharge regulations to accommodate the new SBMs. The paper documents quantifiable benefits of using SBM, including: 1) less waste (SBM can be recycled); 2) low toxicity compared to OBM; 3) reduced drilling time and air emissions compared to WBM; and 4) less down time due to stuck pipe compared to WBM. Even though SBM is more expensive than WBM, data from eight drilling projects using SBM and WBM show that SBM projects were completed in less time for a lower overall cost. (The authors note that the ability to discharge SBM cuttings on-site is important to the economics.)

Yunus, M.N.M., et al, "Environmental Impact of a Flocculant Used to Enhance Solids Transport During Well Bore Clean-Up Operations," SPE 29736 presented at the SPE/EPA Exploration & Production Environmental Conference, Houston, TX, March 27-29, 1995

The authors discuss testing and field trials of a flocculant polymer to improve well bore cleanup for well completion. Flocculation of finer particles reduces the volume of circulating fluid required to clean out the well bore; therefore, reduces completion waste volume. The testing included toxicity evaluation, which indicated the flocculating polymer to be environmentally safe. This application is suited for highly deviated and horizontal well bores which are difficult to clean up.

Svendsen, O., and Toften, J.K., "Use of a Novel Drill-In/Completion Fluid Based on Potassium Formate Brine on the First Open Hole Completion in the Gullfaks Field," SPE/IADC 29409 presented at the 1995 SPE/IADC Drilling Conference, Amsterdam, Netherlands, February 28-March 2, 1995

The authors describe an alternate to oil-based drilling fluid. The application in this instance was combined with an open-hole completion, but potassium formate brine drilling fluid may be a suitable substitute for other applications. The authors state the benefit of the fluid was the possibility to drill, complete and produce an unconsolidated, pressure sensitive reservoir with the

same fluid. They provide a lengthy and thorough discussion of all aspects of the fluid system (e.g., composition, monitoring, and control). With respect to waste minimization, the advantage would be substitution of a less toxic drilling fluid. The authors do not compare the toxicity of the formate brine fluid to oil-based fluid, but do state that it is a better alternative based on worker exposure.

Headley, J.A., et al, "Environmental Safe Water-Based Drilling Fluid to Replace Oil-Based Muds for Shale Stabilization," SPE/IADC 29404 presented at the 1995 SPE/IADC Drilling Conference, Amsterdam, February 28 – March 2, 1995

This paper describes a water-based drilling fluid which is based on methylglucoside (MEG) and salt. The authors state that the new drilling mud "has the potential to replace oil-based mud in many operational areas." The authors provide the results of a field test of the fluid which had good results. Shale sections were stable and the problems typical of drilling gumbo shale with a WBM were minimized. A detailed description of the MEG mud composition is provided, and the authors note that the MEG mud passed toxicity tests. The MEG fluid appears to be a good substitute for OBM.

Sawdon, C.A., et al, "An Integrated Approach to the Development of a Water-Based Mud With Oil-Based Mud Performance," SPE/IADC 29375 presented at the 1995 SPE/IADC Drilling Conference, Amsterdam, Netherlands, February 28-March 2, 1995

The authors describe the composition of a water-based substitute for low-toxicity oil-based mud for use in all but high-temperature applications. In particular, the report pays close attention to all desirable characteristics of OBM, not just shale inhibition. The authors believe "The target of oil based mud performance from an eco-friendly water based mud may never be reached, but it can be approached." As well as describing the specific additives for shale inhibition, lubrication, and corrosion inhibition, the authors discuss the marine toxicity of the mud (which was more than acceptable, and less toxic than OBM). The mud has been field tested in off-shore horizontal drilling, but without using the lubricant and corrosion inhibitor. The authors' discussion of the test indicates that the results were good, with no problems observed. Cost comparisons with OBM were not addressed.

Kenny, P., Hemphill, T., and Bell, G., "Unique Hole Cleaning Capabilities of Ester-Based Drilling Fluid System," SPE 28308 presented at the SPE 69th Annual Technical Conference ands Exhibition, New Orleans, LA, September 25-28, 1994

This paper provides a thorough discussion of the properties of ester-based drilling fluid systems. It should be referenced when studying SPE papers 35330 and 36862.

Clark, R.K., "Impact of Environmental Regulations on Drilling Fluid Technology," SPE 27979, Journal of Petroleum Technology (September 1994) 804-809.

The author presents a fairly thorough overview of the advances in drilling fluid technology between about 1980 and 1994. As the paper's title suggests, the development of substitutes for diesel and mineral oil-based drilling muds have been driven by stricter offshore discharge regulations. The author provides some detail on the toxic components of previously used drilling muds and the formulations for new water-based and synthetic-based muds which provide the performance of oil-based mud. Also discussed is the impact on the use of weighting materials (e.g., barite), spotting fluids, lubricants, biocides, and solids control.

Degouy, D., et al, "Biodegradable Muds: An Attractive Answer to Environmental Legislations Around Offshore Drilling," SPE 26737 presented at the Offshore European Conference, Aberdeen, Scotland, September 7-10, 1993

The authors describe laboratory testing of an ester-based drilling mud which would perform as an adequate substitute for OBM. The authors do not mention actual use of the ester-based mud in drilling. But, the test results indicate the mud should perform as expected. Mud properties cited include: stability up to 140^{O} C: resistance to sea water, drilled solids or cement slurry contamination; and biodegradability.

Reid, P.I., et al, "Reduced Environmental Impact and Improved Drilling Performance With Water-Based Muds Containing Glycols," SPE 25989 presented at the SPE/EPA Exploration & Production Environmental Conference, San Antonio, TX, March 7-10, 1993

Alternatives to oil-based drilling fluids are presented in this paper. Two of a number of glycol systems developed by BP are described. The laboratory development and properties of the fluids containing glycols are described along with the field performance in several BP wells on the UK continental shelf. The performance of these glycol drilling fluids is compared to traditional oil-based drilling fluid. The authors conclude that the glycols have been shown to be nontoxic and environmentally safe and viable for field use. They are easy to mix and maintain and the addition of either of the two described glycols places no restrictions on the use of any other normal mud chemical. (Note: The authors infer that the glycol muds are preferable to cationic polymer muds for several reasons: expense due to high depletion rates; incompatibility with many common mud additives; and concerns raised over the environmental impact of some of the cationic species.)

Halliday, W.S., et al, "Polyglycol and Aluminum Chemistry Drilling Fluid Helps Operator Reach Project Goals," SPE 25702 presented at the 1993 SPE/IADC Drilling Conference, Amsterdam, February 23-25, 1993

The author describes a water-based drilling fluid system with polyglycol additive to control bit balling, organo-aluminum complex drilling fluid additive for shale inhibition (also *see* SPE 25321), and Gilsonite for plugging highly permeable sands. The drilling fluid system,

described in some detail by the author, proved to be an excellent non-toxic substitute for oil-based mud. The drilling fluid was used in an offshore Louisiana project to drill nine sidetracks. The author states that the use of the drilling fluid reduced total mud costs, although a primary factor was that excess mud volumes were stored and used in drilling successive wells. Although this was an offshore application, the described mud system may be useful in certain onshore drilling projects.

Clark, D.E., and Benaissa, S., "Aluminum Chemistry Provides Increased Shale Stability With Environmental Acceptability," SPE 25321 presented at the SPE Asia Pacific Oil & Gas Conference, Singapore, February 8-10, 1993

The authors describe the use of an aluminum complex as a drilling fluid additive for shale inhibition. They note that the previous use of aluminum chelate was problematic because of resulting flocculation and viscosity effects. However, the aluminum complex additive avoids these problems and provides very good shale inhibition properties. Further, the aluminum complex additive works very well with other mud additives. The authors present two case histories (Rocky Mountains area and Gulf of Mexico) which demonstrated the effectiveness of the additive. The cumulative hole from both wells drilled with the aluminum complex additive had a 45% reduction in mud dilution volumes and improved solids control. Although the additive increased the per barrel cost of the drilling fluid, the reduction in dilution rate deceased the overall cost.

Downs, J.D., "Formate Brines: Novel Drilling and Completion Fluids for Demanding Environments," SPE 25177 presented at the SPE International Symposium on Oilfield Chemistry, New Orleans, LA, March 2-5, 1993

The author discusses laboratory tests that indicate formate brines to be a less toxic substitute for halide brines. He discusses the limitations of halide brines and the advantages of formate brines with respect to those limitations. The author does not offer a discussion of the field application of the formate brine drilling fluid. If the lab tests are predictive, the formate brine would be useful in high temperature, offer shale inhibition, and be compatible with many additives (e.g., polymers).

Carter, T.S., and Faul, G.L., "Successful Application of the AOBM System in a Deep West Texas Well," SPE 24590 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, DC, October 4-7, 1992

Oil muds are usually used in drilling because of their improved hole stability in thick shale sections uncased for 50 or more days, improved lubricity, high temperature stability, and reuse of the mud system on subsequent wells. This paper describes the successful application of an All Oil-Base Mud (AOBM) system. However, based on both engineering and environmental criteria, the liquid phase of this AOBM system was prepared with a low viscosity/low toxicity-base oil offering unique properties. The unique design of the AOBM combined with proper bit

selection and successful downhole motor runs achieved higher penetration rates compared to offset wells in the area. This was the first drilling application of this mud design in an area of West Texas where the conventional oil mud system was formulated with diesel and an emulsified brine phase.

Elward-Berry J., and Darby J.B., "Rheologically Stable, Nontoxic, High-Temperature Water-Base Drilling Fluid," SPE 24589 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, DC, October 4-7, 1992

The authors describe the development of a stable high-temperature water-based drilling fluid. The drilling fluid has been used in offshore and land operations at depths with temperatures as high as 420°F. The authors provide a detailed discussion of the problems associated with water-based, bentonite fluids in deep, high temperature wells, and how the new fluid was designed to overcome the problems. The new fluid tolerates contamination, as well as high temperature, and it inhibits bentonite flocculation. The new fluid was developed using commercially available materials of minimal toxicity. The paper also includes fluid formulation and a discussion of field test results. Bioassay and lab testing of field samples indicate that the drilling fluid exhibits LC50 values at or above 400,000 ppm. This paper is an excellent reference for an operator looking for an alternative to using an oil-based fluid in a high-temperature well.

Beihoffer, et al, "Field Testing of a Cationic Polymer/Brine Drilling Fluid in the North Sea," SPE 24588 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, DC, October 4-7, 1992

The search for alternatives to oil-based mud (OBM) has led to the development and field testing of a variety of new ideas in drilling fluid systems and fluid additives. This paper discusses the field testing of a cationic polymer/brine drilling fluid (CBF) on seven wells drilled in the North Sea. Field data are presented along with a discussion of the performance of CBF, including benefits, limitations and costs as compared to oil-based and conventional water-based muds. Advantages of CBF over conventional water-based fluids include: ease of maintenance; contamination resistance; and ability to independently control fluid properties. The information provided in this paper can assist operators in evaluating alternatives to oil-based fluids in areas where the use of OBM is restricted.

Bleier, R., et al, "Drilling Fluids: Making Peace with the Environment," SPE 24553 *Journal of Petroleum Technology* (January 1993)

Minimizing environmental impact involves reducing levels of toxic components in drilling fluids, as well as waste minimization and recycling. This paper assesses the current state of technology and the likely directions for the future. The constructive role of regulatory agencies in recognizing, fostering, and encouraging the use of emerging technologies, as opposed to blanket prohibitions, also is discussed. In addition, tradeoffs between environmentally desired features, e.g., lower toxicity, but larger waste volumes, also are addressed.

Jacques, D.F, et al, "A Comparison of Field Drilling Experience With Low Viscosity Mineral Oil and Diesel Muds," IADC/SPE 23881 presented at the 1992 IADC/SPE Drilling Conference, New Orleans, Louisiana, February 18-21, 1992

The development of two low-viscosity, low-aromatic, low-toxicity enhanced mud oils (EMO) is discussed as an alternative to diesel and mineral oil muds. The EMO's contain only 0.25% aromatics compared to 12% for mineral oils and 30-60% for diesel oils. The EMO's are extremely insoluble in water which results in an LC50 greater than 1,000,000 compared to about 2,000 for diesel oil. The authors discuss field trials that show the EMO's contribute to increased penetration rates in various formation types compared to the diesel and mineral oil muds. Although the EMO's are more expensive, the increased cost may be offset by reductions in mud and cuttings disposal costs.

Enright, D.P, et al, "An Environmentally Safe Water-Based Alternative to Oil Muds," SPE 21937, *SPE Drilling Engineering* (March 1992) 15-20

A mechanism describing the onset of bit balling is given. On the basis of this mechanism, a new copolymer/polypropylene glycol (COP/PPG) water-based drilling fluid was developed. The properties of this drilling fluid are described, and field test comparisons are made with water- and oil-based fluids. The conclusion presented is that the COP/PPG drilling fluid system is environmentally safe and is a viable alternative for oil-based fluids in both fresh and seawater environments.

Oakley, D.J., et al, "Cooperative Research – A Route To Reduce the Environmental Impact of Drilling Fluids," SPE 20885, *SPE Drilling Engineering* (September 1992) 186-190

The authors describe how Amerada Hess Ltd. and International Drilling Fluids Ltd. cooperated by extending laboratory developments into controlled field trials and how feedback from the field allowed rapid progress toward drilling fluid performance and ecological goals. The effort resulted in the development of a novel, oil-free, highly inhibitive, water-based drilling fluid that was satisfactorily substituted for oil-based drilling fluid. Also, invert-emulsion and direct-emulsion drilling fluids with low oil-water ratios were developed for low oil-on-cuttings application. The authors provide detailed descriptions of the development of the fluids. These drilling fluids were tailored for use in Block 15/21 on the U.K. Continental Shelf; however, they may be applicable at other locations where the use of oil-based mud may be a concern.

Bland, R., "Water-based Glycol Systems Acceptable Substitute for Oil-based Muds," *Oil and Gas Journal* (June 29, 1992)

The use of water-based muds using polypropylene glycols in place of oil-based muds to reduce shale swelling and maintain the mechanical integrity of hydratable shales is discussed. The author states that polypropylene glycol muds have low toxicity levels (LC50 > 200,000),

minimize torque and drag in deviated holes, reduce gas hydrate formation temperatures, reduce the risk of differential sticking, and can be used as a spotting fluid.

Park, L.S., "A New Chrome-Free Lignosulfonate Thinner: Performance Without Environmental Concerns," SPE 16281, SPE Drilling Engineering (September 1988) 311-314

The author, of M-I Drilling Fluids Co., describes a chrome-free lignosulfonate drilling fluid additive which offers performance equivalent to chrome lignosulfonate. The additive a titanium-based lignosulfonate, which the author states will control rheological properties of drilling fluids as well as chromium lignosulfonate. The author states that the titanium-based additive does not pose the problems observed with previous chrome-free lignosulfonates. Problems included less tolerance to solids; more sensitive to high temperature; inferior performance when added to seawater and other inhibited drilling fluids; lack of gel-strength control at high temperature; and sensitivity to pH variation. This additive is a good product substitution opportunity for chrome lignosulfonate, which is toxic in the environment. Because this additive was developed in the late 1980's, improved substitute additives for chrome lignosulfonate have possibly been developed and commercialized.

2.6 OTHER DRILLING SYSTEMS THAT MAY MINIMIZE WASTE

Drilling With Casing

Drilling with casing results in the reduction of hole size. Therefore, it results in the reduction of drill cuttings and, under certain circumstances, waste drilling mud. The following papers describe the system's advantages (e.g., cost reduction) and disadvantages (e.g., difficult to run open-hole logs). Drilling with casing is appropriate only in limited circumstances. These papers offer some guidance regarding the proper application of drilling with casing.

Gordon, D, et al, "Underbalanced Drilling with Casing Evolution in the South Texas Vicksburg," SPE 84173 presented at the SPE Annual Technical Conference and Exhibition, Denver, CO, October 5-8, 2003

The authors describe Shell E&P Company's development of an underbalanced drilling with casing program in the Vicksburg Formation. The development of the drilling program was prompted by problems specific to the field, such as intermingled high-pressure gas sands and low-pressure depleted sands and the economics a mature field. The paper includes a thorough description of the drilling program's development and explains the encountered problems and solutions and the system's limitations. The end result was a successful system for drilling and completing development wells with casing. Drilling with casing resulted in a "monobore" (i.e., reduced hole size). Although the authors do not address drilling waste generation, it is apparent that the reducing the hole size also reduced the quantity of drill cuttings generated as waste. It is not clear form reading the paper that drilling mud quantities were also reduced.

Tessari, R.M., and Madell, G., "Casing Drilling - A Revolutionary Approach to Reducing Well Costs," SPE 52789 presented at the 1999 SPE/IADC Drilling Conference, Amsterdam, Holland, March 9-11, 1999

Abstract: Rotary drilling, as we know it today, replaced percussion or cable tool drilling in the 1930's. Since that time, wells have been drilled using a drill string consisting of drill pipe, drill collars, a bit and varying downhole tools known as a "bottom hole assembly" (BHA). When the bit wears out or the BHA has to be changed, the process of "tripping" is commenced. Tripping consists of hoisting the drill string out of the well in lengths of 30, 60, or 90 feet. This process is labour, equipment and energy intensive and takes up to 35% of the total time to drill a well. In addition to the productive drilling time lost to tripping, unscheduled events during tripping can make the drilling process even more inefficient and even lead to losing the well. This paper describes the process of a three-year research and development project to develop and commercialize casing drilling. Casing drilling will use standard oilfield casing to both drill and simultaneously case the well. Bottom hole assemblies will be retrieved on wire line up the inside of the casing. Casing drilling will eliminate the use of drill pipe, significantly reduce tripping times and reduce time lost due to unscheduled events such as reaming, fishing and taking kicks while tripping. This paper describes the tools to be used, including a special purpose built drilling rig for this process. The anticipated results of drilling with casing are discussed and specific conclusions include up to 30% savings in well costs feasible through drilling with casing.

Drilling With Coiled Tubing

Coiled tubing (CT) technology has advanced over the years. Since the first CT drilling in the early 1990s, more companies have established CT drilling as a viable alternative to conventional rotary drilling. Also, CT has been proven to be an effective way to sidetrack a well through tubing (however, most applications appear to have been through 4.5 inch or greater tubing). As well, CT has been used for well stimulation and workover operations. CT tools (e.g., BHAs and drill motors) are continually being improved. In general, the use of CT can reduce the overall quantity of waste generated by a drilling, well stimulation, or well workover operation. For example, a through tubing sidetrack eliminates the need to pull tubing and other downhole equipment. An additional benefit of CT is the ability to safely drill underbalanced; therefore, a well completion may be improved. Also, CT drilling is especially suitable for slim-hole drilling.

The following technical papers and articles are selected to illustrate the feasibility and advantages of CT. Please note that there are numerous technical papers (e.g., Society of Petroleum Engineers), which discuss the use of CT in many different applications. Many are referenced below, and some are included without annotation. Also, numerous papers and articles address specific CT technologies such as bits, CT materials (e.g., composite CT), CT fatigue analysis, and specialized tools. An operator interested in investigating the use of CT should conduct further research.

U.S. DOE and MMS, "Sound Coiled-Tubing Drilling Practices," U.S. Department of Energy National Energy Technology Laboratory and U.S. Department of the Interior Minerals Management Service, DOE/NETL-2002/1170 (September 2001)

This U.S. DOE manual does not specifically address waste management or minimization in coiled tubing drilling (CTD). But, it is a useful tool for CTD engineers and supervisors in planning, designing and performing safe, successful CTD operations. (Note: This DOE manual is available on the DOE web site at: http://www.netl.doe.gov/scng/explore/ref-shelf/CTD.pdf)

Gaddy, D.E., "Coiled-Tubing Drilling Technologies Target Niche Market, *Oil and Gas Journal* (January 20, 2000) 29-38

Coiled-tubing drilling (CTD) has been successfully used by ARCO, BP Amoco, PLC and Petroleum Development Oman (PDO) to access hard to reach, overlooked, and depleted reservoirs from existing well bores. Much of this work involves sidetrack, slim-hole, under balanced, and through tubing applications that provide distinct economic and operational advantages over conventional methods. This article presents the experiences and activities of the main players in the coiled tubing operations. The paper gives an overview of the history and current use of the CTD systems and the philosophy of the companies that operate the systems.

Leising, L.J., et al, "Extending the Reach of Coiled Tubing Drilling (Thrusters, Equalizers and Tractors)," SPE 37656 presented at the 1997 SPE/IADC Drilling Conference, Amsterdam, The Netherlands, March 4-6, 1997

The authors compare the various weight transfer devices and methods used (circa 1997) to enhance the reach of coiled tubing in horizontal wells. The paper includes the results of field testing a solid BHA, bumper sub (thruster), and weight on bit (WOB) equalizer.

Donald, D. et al, "Planning, Execution and Review of Brent's First Coil Tubing Drilled Well," SPE 37655 presented at the 1997 SPE/IADC Drilling Conference, Amsterdam, The Netherlands, March 4-6, 1997

The authors describe a project to demonstrate the viability of coiled tubing drilling (CTD) for use in accessing relatively small reservoirs. A demonstration well was successfully sidetracked, drilled to TD, and completed using CTD. This project is applicable to offshore drilling and production, but should offer useful information for any CTD.

Anderson, D.R., et al, "A New, Integrated, Wireline-Steerable, Bottomhole Assembly Brings Rotary Drilling-Like Capabilities to Coiled Tubing Drilling," SPE 37654 presented at the 1997 SPE/IADC Drilling Conference, Amsterdam, The Netherlands, March 4-6, 1997

This paper describes a new, integrated system which uses wireline inside the coil to orientate the power section of the BHA electrically. The same wireline is used to transmit data from the sensor package (improved over mud pulse telemetry). The tool allows adjustments as fine as one degree in either direction or continuous rotation of the BHA power section to permit a rotational element to be introduced into what is normally a sliding operation. The benefits are directional stability and improved rate of penetration by reducing tortuosity. The authors discuss the advantages of the new BHA over previous designs.

Young, L.M., et al, "Fit For Purpose Reeled Systems: A Case History," SPE 37653 presented at the 1997 SPE/IADC Drilling Conference, Amsterdam, The Netherlands, March 4-6, 1997

This paper describes, through a review of the benefits of coiled tubing drilling (CTD), the development of "fit for purpose reeled systems." These systems integrate the benefits of continuous tubing, the ability to snub into live wells and the option to rotary drill using drill pipe. The systems have been designed for use over a wide range of applications from re-entry drilling, underbalanced drilling and field maintenance. A case history of the first use of CTD techniques in the Gulf of Mexico is discussed.

Strunk, Chris, "Slim Hole, Coiled Tubing Combine to Enhance Well Economics," *The American Oil and Gas Reporter* (February 1997) 37-42

The author discusses the use of coiled tubing for drilling slim holes. As with slim-hole drilling, the author notes varying degrees of success using CTD. One company quoted by the author stated that in certain projects, CTD has reduced total well costs by about 25%. Other quoted operators were less enthusiastic about CTD new wells, but instead had found CT to be advantageous for well re-entry and sidetracking. The author concludes that "In the near term, it's still going to be primarily a re-entry technology," and that there could be "up to 'hundreds of thousands' of wells" suitable for re-entry using slim-hole technology. If so, CTD will likely be the technology used to accomplish the re-entries.

Hearn, D.D., et al, "Brief: Coiled-Tubing Window Milling," SPE 37381, *Journal of Petroleum Technology* (September 1996) 833-834

The authors describe Arco's use of coiled tubing to mill windows through tubing for sidetracking wells in Alaska. This technique, which uses a cement kickoff plug, eliminates the need to pull tubing, thus reduces costs as well as associated waste generation. The cost information provided by the authors is applicable to the circumstances at the North Slope in Alaska; however, the technique should be considered in other areas. (Note: This article is based on SPE 35126

by the same authors and presented at the 1996 IADC/Drilling Conference, New Orleans, LA, March 12-15, 1996. *See* SPE 35126 for more detail.)

Elsborg, C. et al, "High Penetration Rate Drilling with Coiled Tubing," SPE 37074 presented at the 1996 SPE International Conference on Horizontal Well Technology, Calgary, Canada, November 18-20, 1996

Annotation to be added.

Scherschel, S.R., and Graves, D.G., "Underbalanced Drilling with Coiled Tubing – Challenges and Solutions," SPE 37062 presented at the 1996 SPE International Conference on Horizontal Well Technology, Calgary, Canada, November 18-20, 1996

This paper provides an excellent overview of the use of coiled tubing for underbalanced drilling. The authors describe the surface and downhole equipment and the operation of the CT system. They also discuss the advantages, capabilities, and limitations of CT. With respect to waste minimization, the authors note that underbalanced CT drilling eliminates the need to use fluid additives to produce filter cake and increasing viscosity. This minimizes the handling of additional chemicals.

Moon, R.G., et al, "Shallow Gas Well Drilling with Coiled Tubing in the San Juan Basin," SPE 36463 presented at the 1996 SPE Annual Technical Conference and Exhibition, Denver, CO, October 6-9, 1996

The authors describe a multiwell project which provides documentation indicating that coiled tubing can be an alternative to the conventional rotary rig. The project used workover rigs to drill surface holes and set casing, while using the coiled tubing unit to drill the productive zone. In this project the wells were relatively shallow (1,500 feet to 2,400 feet). The authors describe the geology of the drilled interval and the design of the coiled tubing drilling system, including mud design, the handle the circumstances. Also, they describe the problems encountered and lessons learned and applied. The efficiency of the process improved with each well. One notable feature of the process was the use of trailer-mounted mud tank and closed mud circulating system. This combined with the use of the workover and coiled tubing rig reduced the operational footprint.

Oosterling, P., and Faure, A.M., "Brief: The Reeled System: A Step Toward Improving Cost Efficiency of Drilling Through Introduction of New Technology," SPE 36067, *Journal of Petroleum Technology* (March 1996) 247-248

This article provides an overview of coiled tubing use in 1995 and a discussion of the future of coiled tubing used in drilling, completions, and production. The authors note certain environmental advantages of drilling underbalanced with coiled tubing, such as reduced footprint and reduced spills (due to required closed-loop mud system). Of interest, the authors foresee the

potential of expandable tubing and casing and its application to coiled tubing. (Note: This paper is derived from an earlier paper which provides more detail: Faure, A.M., et al, "Steps Toward a Comprehensive Reeled Tube Drilling System," SPE/IADC 29358 presented at the 1995 SPE/IADC Drilling Conference, Amsterdam, February 28-March 2, 1995.)

Gary, S.C., and Doremus, D.M., "Technical and Economic Feasibility of Coiled Tubing Drilling," SPE 30490 presented at the SPE annual Technical Conference and Exhibition, Dallas, TX, October 22-25, 1995

Although this paper was presented in 1995 (coiled tubing technology has advanced in the meantime), it is still useful for gaining an understanding of the various considerations necessary to evaluate the technical and economical feasibility of coiled tubing drilling.

Faure, A.M., et al, "Coiled Tubing Drilling: A Means To Minimize Environmental Impact," SPE 27156 presented at the Second International Conference on Health, Safety & Environment in Oil & Gas Exploration & Production, Jakarta, Indonesia, January 25-27, 1994

The author describes the use of coiled tubing in a field tests to drill a vertical well and a horizontal sidetrack. These field trials were among the first to test the feasibility of coiled tubing in drilling (CTD). The field tests were generally successful and identified shortcomings that the authors offered as a focus for future research and development. Waste minimization benefits were gained in the field tests, primarily about a 70% reduction of drilling fluid and cuttings quantities. Other environmental advantages were reduced footprint, consumption of fuel, air emissions, and noise levels. Primary advantages of coiled tubing drilling are that it accommodates underbalanced drilling which reduces formation damage and the need for later well treatment (e.g., acid stimulation), and that it offers the possibility of drilling "monoholes."

Faure, A.M., et al, "Horizontal Drilling With Coiled Tubing: A Look at Potential Application to North Sea Mature Fields in Light of Experience Onshore The Netherlands, SPE 26715 presented at the Offshore European Conference, Aberdeen, Scotland, September 7-10 1993

The authors offer similar arguments in favor of coiled tubing drilling and discuss in more detail the horizontal sidetrack field trial presented in SPE 27156.

Hightower, C.M., et al, "Coiled-Tubing Sidetrack: Slaughter Field Case History," SPE 26335 presented at the 68th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Houston, TX, October 3-6, 1993

The authors describe an early, successful use of coiled tubing drilling to sidetrack an oil well in West Texas.

Leising, L.J., and Newman, K.R., "Coiled-Tubing Drilling," SEP 24594, *SPE Drilling & Completion* (December 1993) 227-232

The authors present a thorough engineering analysis of coiled tubing drilling (CTD). The paper discusses the use of coiled tubing in re-entries, horizontal drilling, and drilling new wells. They note the limitations of coiled-tubing drilling cited in SPE 27156, however, offer a detailed discussion of a technical feasibility procedure to determine if coiled tubing can be used for a particular project. The authors cite numerous references which are useful in performing a technical feasibility analysis (e.g., a tubing forces model and a tubing life prediction model). The authors conclude that "the main limitations to CTD are reel size/weight, maximum WOB/frictional drag, fatigue and hydraulics." At the time the authors prepared this paper, they knew of 24 instances of CTD application (only 5 were new wells). This paper is a very good reference for anyone considering the use of CTD.

Traonmilin, E.M., et al, "First Field Trial of a Coiled Tubing for Exploration Drilling," IADC/SPE 23876 presented at the 1992 IADC/SPE Drilling Conference, New Orleans, LA, February 18-21, 1992

This paper discusses the first trial of open-hole coil tubing drilling (CTD) conducted by Elf-Aquitane with Dowell Schlumberger in the Paris Basin. The purpose was to determine the feasibility of using coiled tubing units to drill slim holes instead of the conventional rotary rig. The trial verified that CTD was feasible for use in some specific prospects. The paper describes the specific drilling conditions and the project organization including the choice of well, choice of equipment, surface layout, well prognosis, and bottom hole assemblies. The use of a coiled tubing unit instead of conventional drilling rig would result in less waste being generated. For example, roads to the site could be smaller and require less preparation to carry heavy equipment, the drill pad is smaller, the drill crew is smaller and there is in general a minimization of all parameters.

Ramos, A.B., Jr., et al, "Horizontal Slim-Hole Drilling With Coiled Tubing: An Operator's Experience," SPE 23875, *Journal of Petroleum Technology* (October 1992) 1119-1125

The authors describe Oryx Energy's attempts to use CTD for horizontal sidetracks in the Austin Chalk. This project was one of the first to use CT and preceded the improvement of CT downhole tools. Oryx encountered numerous difficulties, the value of which was to highlight areas which needed further development and refinement. The authors did not give up, however, and had another CTD project planned. They recognized the benefits of CTD which have been confirmed in more recent SPE papers.

Fultz, J.D., and Pittard, F.J., "Openhole Drilling Using Coiled Tubing and a Positive Displacement Mud Motor," SPE 20459 presented at the 65th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, New Orleans, LA, September 23-26, 1990

This very early paper on coiled tubing drilling established the technology's feasibility.

The following additional coiled tubing references are provided without annotation.

Elsborg, C.C., et al, "Large Diameter Coiled Tubing Drilling," SPE 37053 presented at the1996 SPE International Conference on Horizontal Well Technology, Calgary, Canada, November 18-20, 1996

Atherton, G.M., and Davis, M., "Coiled Tubing Drilling of Horizontal Re-entry Wells, UK Land," SPE 35546 presented at the European Production Operations Conference and Exhibition, Stavanger, Norway, April 16-17, 1996

Wu, J., "Coiled Tubing Working Life Prediction," SPE 29461 presented at the Production Operations Symposium, Oklahoma City, OK, April 2-4, 1995

Eide, E., et al, "Further Advances in Coiled Tubing Drilling," SPE 28866 presented at the European Petroleum Conference, London, U.K., October 25-27, 1994

Newman, K.R., and Doremus, D.M., "Hybrid Coiled Tubing/Snubbing Drilling and Completion System," SPE 28300 presented at the SPE 69th Annual Technical Conference and Exhibition, New Orleans, LA, September 25-28, 1994

Leising, L.J., and Rike, E.A., "Coiled-Tubing Case Histories," SPE 27433 presented at the 1994 IADC/SPE Drilling Conference, Dallas, TX, February 15-18, 1994

Drilling With A Snubbing Unit

Hodgson, R. "Snubbing Units: A Viable Alternative to Conventional Drilling Rig and Coiled Tubing Technology, SPE 30408 presented at Offshore Europe 1995, Aberdeen, Scotland, September 5-8, 1995

The author presents an interesting alternative for drilling and completing wells; using a snubbing unit. Snubbing units have been used for a long time, but primarily as a tool to kill wells or to control blowouts. But, the advantages of a snubbing unit are the same as for coiled tubing. As well as providing the ability to drill and complete underbalanced and to workover live wells, the snubbing unit has the additional capability of rotating the tubing string. Tubing also has certain advantages over coiled tubing, such as greater reach and ability to bear weight-on-bit. The author describes the uses of snubbing units in offshore operations in the North Sea, which include live well gravel packing, well stimulation, zonal isolations, underbalanced tubing

conveyed perforating (TCP), and tubing replacement workovers. Because the examples are for offshore platform operations, many of the advantages and economic benefits the author cites may not apply to land operations. However, the paper is a useful resource for learning about drilling, completion and workover techniques which can gain waste reduction benefits. As well as allowing underbalanced drilling, the use of a snubbing unit can eliminate the need for completion and kill fluids, which reduces waste generation (and, reduces formation damage as well). Also, the "environmental footprint" of a snubbing unit is smaller than that of a conventional rotary rig. Coiled tubing remains a very useful technique, but snubbing units may prove more effective under certain circumstances.

Drilling With Air

Rusnak, J.A., "A Closed Circulating System for Air Drilling," SPE 39302 presented at the IADC/SPE Drilling Conference, Dallas, TX, March 3-6, 1998

This paper has not been reviewed for this bibliography. According to the abstract, this paper discusses an alternative to the practice of exhausting all air drilling fluids into an earthen waste pit. The abstract states "A system has been developed to eliminate the waste pit without otherwise changing the basic drilling process and conditions."

Rusnak, J.A., "Apparatus Eliminates Earthen Pits in Air-Drilling Operations," *Oil and Gas Journal* (August 17, 1998) 104-109

The author, of New Prospect Drilling Co., describes a system that eliminates the earthen waste pit during air drilling and the environmental problems associated with earthen pits. The system is equipped to separate, treat, and transfer liquid and solid portions of the drilling effluent while exhausting only gaseous components, such as air and methane to be flared or otherwise treated. This system was successfully tested on wells being air drilled in the Arkoma basin of northwest Arkansas and southeast Oklahoma. Field testing showed that the system can handle continuous liquid volumes of 90 bbl/hr with capability of handling higher volumes during peak load and continuous solid volumes of 14 bbl/hr. The author does not discuss the management of separated liquids; however, this system accommodates the reuse of the liquids. At the time, the cost of operating the system ranged between $500 to $1,000 per day.

Note: This article is based on IADC/SPE 39302 presented at the IADC/SPE Drilling Conference, Dallas, Texas, March 3-6, 1998.

Temple, R.C., et al, "An Experimental Study on Pneumatic Transport of Solids in a Vertical Well Bore Annulus," SPE 37327 presented at the SPE Eastern Regional Meeting, Columbus, Ohio, October 23-25, 1996

The authors discuss the Drilling-Hydraulic Research Center's (Penn State University) research on the hydrodynamics associated with air drilling. The authors offer results of their studies

which can help operators identify the optimum air flow for wellbore cleanout and cuttings removal. The reported research does not address a specific waste minimization technique. However, the authors note that air drilling is underutilized even though it offers environmental benefits. They estimate that "about 30% of all wells drilled in the U.S. could use air drilling successfully," but "(p)resently, the actual figure is about 10%." The authors state, "Where feasible, it makes sense from both an economic and environmental prospective to use air." In particular, air drilling eliminates drilling fluid (conventional mud) waste. Other papers in this section support the environmental advantages of air drilling.

Numerous SPE technical papers discuss well bore hydraulics and air volume requirements. An operator interested in air drilling may consider referring to the following references offered without annotation. It may be assumed that more recent papers offer a more sophisticated discussion of this subject.

Guo, B., et al, "Volume Requirements for Directional Air Drilling," IADC/SPE 27510 presented at the 1994 IADC/SPE Drilling Conference, Dallas, TX, February 15-18, 1994

Adewumi, M.A., et al, "Fundamental Study Makes Improved Air Drilling Technology Possible," SPE 26893 presented at the 1993 Eastern Regional Conference & Exhibition, Pittsburgh, PA, November 2-4, 1993

Tian, S., and Adewumi, M.A., "A New Method of Estimating Mixture Density in Air Drilling," SPE 24960, unsolicited paper (March 23, 1992)

Johnson, P.W., "Design Techniques in Air and Gas Drilling: Cleaning Criteria and Minimum Flowing Pressure Gradients," SPE 23550, unsolicited paper (1991)

Tian, S., and Adewumi, M.A., "Development of Hydrodynamic-Model-Based Air-Drilling Design Procedures," SPE 23426, *SPE Drilling Engineering* (December 1992) 241-246

Tian, S., and Adewumi, M.A., "Multiphase Hydrodynamic Model Predicts Important Phenomena I Air-Drilling Hydraulics," SPE 21559, *SPE Drilling Engineering* (June 1991) 145-152

Adewumi, M.A., and Tian, S., "Analysis of Air Drilling Hydraulics," SPE 21277 presented at the SPE Eastern Regional Meeting, Columbus, OH, October 31-November 2, 1990

Supon, S.B., and Adewumi, M.A., " An Experimental Study of the Annulus Pressure Drop in a Simulated Air-Drilling Operation," SPE 19334, *SPE Drilling Engineering* (March 1991) 74-80

Adewumi. M.A., and Tian, S., "Hydrodynamic Modeling of Wellbore Hydraulics in Air Drilling," SPE 19333 presented at the SPE Eastern Regional Meeting, Morgantown, WV, October 24-27, 1989

Sharma, M.P., "A Microcomputer Model for Cutting Transport in Air Drilling," SPE 16500 presented at the Petroleum Industry Applications of Microcomputers, Del Lago on Lake Conroe, TX, June 23-26, 1987

Wolcott, D.S., "Analysis of Air Drilling Circulating Systems With Application to Air Volume Requirement Estimation," SPE 15950 presented at the SPE Eastern Regional Meeting, Columbus, OH, November 12-14, 1986

Sheffield, J.S., and Sitzman, J.J., "Air Drilling in the Midcontinent and Rocky Mountain Areas," SPE/IADC 13490 presented at the SPE/IADC 1985 Drilling Conference, New Orleans, LA, March 6-8, 1985

This paper is useful in that the authors describe Exxon's practical experiences with air drilling. The paper explains when air drilling is feasible and situations where air drilling should not be considered. The authors do not describe waste generation and management in air drilling, but note cost savings realized from its use.

Drilling With Cable Tools

Operators who have not considered cable tool drilling, may find the information in the following paper of interest. In certain areas and geology, cable tool drilling may prove to be feasible and cost-effective.

Hayes, J.P., and Fisher P., "The Environmental, Reservoir, and Operational Advantages of Cable Tool Drilling Natural Gas Storage Wells," SPE 26901 presented at the 1993 Eastern Regional Conference & Exhibition, Pittsburgh, PA, November 2-4, 1993

"This paper discusses cable tool drilling as an alternative to rotary drilling, and examines the environmental, reservoir, and operational advantages of cable tool drilling natural gas storage wells." The paper presents an interesting concept – using an old technology. In this instance, Union Gas, Ltd., drilled wells in relatively shallow dolomite pinnacle reef structures (about 1,700 feet) in the Michigan Basin. The authors discuss the cable tool drilling process. With respect to waste minimization, the discussed cable tool drilling reduced waste considerably, particularly waste drilling fluid. The small quantity of waste allowed the use of tanks, eliminating pits. The authors also note the disadvantages of cable tool drilling. The cable tool drilling was cost effective.

2.7 DRILLING AND COMPLETING WITH EXPANDABLE CASING

The use of expandable casing allows wells to be drilled with a relatively constant borehole size once beneath surface casing. This type of drilling process is a relatively new technology, although expandable casing has been used to some extent in sidetracks of existing wells. The ability to drill a relatively constant hole size offers several benefits, which are described in the

following papers and articles. Waste drilling mud and cuttings quantities are significantly minimized. This technology was primarily developed for use in offshore drilling, because space and load requirements on offshore rigs are greatly reduced (thus greatly reducing costs). However, the technology is also attractive for onshore drilling where cost effectiveness and waste minimization benefits should also be realized.

Campo, D., et al, "Monodiameter Drilling Liner – From Concept to Reality," SPE/IADC 79790 presented at the SPE/IADC Drilling Conference, Amsterdam, The Netherlands, February 19-21, 2003

The authors, of Shell E&P Company and Enventure Global Technology, provide a comprehensive overview of drilling and completing wells with expandable casing, which they refer to as "MonoDiameter." They describe the technical evolution, including previous experience with expansion of different size casing in different configurations. The authors explain the limitations of expandable casing with respect to size, which is related to the strength limit of the pipe, and current bit technology for hole opening (for the expanded casing bell). The authors provide a summary of the successful prototype well drilled and completed using the MonoDiameter technology. The waste minimization benefits are cited as reduction in emissions and reduction in the disposal of cuttings (reduced 59%) and fluids. Also realized are a reduction in consumption of natural resources and well construction consumables, which indirectly reduces waste generation. The quantity of required drilling fluid is reduced 44%, cement is reduced 42%, casing tonnage is reduced 42%.

Sumrow,, M., "Shell drills world's first MonoDiameter well in South Texas," *Oil and Gas Journal* (October 21, 2002) 53-55

This article highlights the MonoDiameter drilling technology described in SPE/IADC 79790. The author provides the MonoDiameter developers explanation of the technology's potential benefits. "It could shrink the operational footprint by 75%, generate fewer emissions by reducing rig size, consume 20% less drilling mud, and generate up to 50% fewer cuttings." The article also provides information on the MonoDiameter prototype well described in SPE 79790.

2.8 DRILLING "SLIM" HOLES

Slimhole drilling offers the benefit of reduced waste generation. Smaller hole sizes generate less cuttings and require reduced quantities of drilling fluid. In combination with coiled tubing drilling and the new expandable casing, slim hole drilling could have a significant impact on drilling waste generation. The following papers and articles offer an overview of slimhole drilling and examples of its cost-effective use. Importantly, the papers and articles also point out the limitations of slimhole drilling.

Cohen, J.H., et al, "Slimhole Drilling System Doubles Penetration Rates," *Oil and Gas Journal* (April 10, 2000) 67-69

The authors describe a new, reliable, high-powered, slimhole motor developed for the U.S. Department of Energy (DOE). The new motor and bit drills twice as fast as conventional motors and bits. The motor makes slimhole drilling more attractive (and probably would be a good match with coiled tubing). Waste minimization results in that the amount of drilling mud, cuttings, and cement are reduced in slimhole drilling.

The DOE slimhole drilling system consists of a double length, high-power, positive – displacement motor (PDM) coupled with a hybrid polycrystalline diamond compact drill bit embedded with thermally stable diamond cutters. The 3 3/8 inch diameter motor develops 73 horsepower compared to 28 horsepower for a conventional motor. The authors discuss tests conducted by the Drilling Research Center and the Gas Research Institute which confirmed that the PDM delivers twice the torque and power of conventional motors, while the hybrid bits undergo minimal wear. The tests were conduced in very hard, as well as soft, formations. In each test the new system drilled twice as fast as a conventional system.

Note: This article is based on SPE 59154 presented at the 2000 IADC/SPE Drilling Conference, New Orleans, Louisiana, February 23-25, 2000.

Groenevelt, P. et al, "Slim Hole Exploration: One Year Experience in Romania," SPE 37657 presented at the 1997 SPE/IADC Drilling Conference, Amsterdam, The Netherlands, March 4-6, 1997

The authors describe the design and use of an integrated drilling and coring system. This slim hole rig, which can drill small diameter holes to depths of 3,500 meters (about 11,500 feet), is called FORASLIM 1. The rig is designed to provide a lower cost means of drilling in remote onshore areas while minimizing environmental impact and improving efficiency and safety.

Strunk, Chris, "Slim Hole, Coiled Tubing Combine to Enhance Well Economics," *The American Oil and Gas Reporter* (February 1997) 37-42

This article discusses the various economic and technical aspects of slim hole drilling which existed in 1997. Under certain circumstances, drilling smaller holes can improve project economics. The author states that slim hole technology is one of the fastest growing segments of the industry. In general, a "slim hole" is a well with production casing of 4 inches OD or less in a production hole of 6 inches OD or less. The author discusses some of the problems involved in slim hole drilling, such as bit life. In the article, representatives of several companies offer their experiences and perspectives on slim hole drilling. In some instances, it has proven economical and in other instances it has not offered as many benefits. Although this article was based on the economic advantages of slim hole drilling, the environmental advantages are readily apparent. The overall footprint of the well is smaller, all tangible items (e.g., tubulars) are smaller, there is less drilling fluid and cuttings waste, reduced water requirements, and in general a marked

reduction in environmental impact. The author generally concludes that slim hole drilling technology will improve in the future; therefore, operators should investigate the feasibility of slim hole drilling.

Kroell, E., and Spoerker, H.F., "Brief: Slimhole Completion and Production," SPE 37375, *Journal of Petroleum Technology* (September 1996) 846-847

This paper is useful to any operator considering slimhole drilling. The authors provide a comprehensive overview of the feasibility of slimhole completions and production. They address numerous issues and considerations, such as perforation systems, artificial lift, stimulation, and workovers. The paper also addresses production limitations of slimhole completions. (Note: This paper is derived from an earlier paper which provides more detail: Kroell, E., and Spoerker, H.F., "Slimhole Completion and Production – What To Do After We Drilled The Well," SPE/IADC 35129 presented at the SPE/IADC Drilling Conference, New Orleans, LA, March 12-15, 1996.)

Millheim, K.K., et al, "Slim Hole Drilling Technology – Pat, Present, Future," SPE 30151 presented at the SPE PetroVietnam '95, Ho Chi Minh City, Vietnam, March 1-3, 1995

This paper provides a lengthy discussion of the status of slimhole drilling in 1995. The authors list past successful slimhole drilling efforts and describe the benefits and pitfalls of the technology. Of particular interest, the authors discuss the industry's perceptions of slimhole drilling and the influence of those perceptions on its use. The authors offer the opinion that "Most of today's [circa 1995] drilling (70-80%) could be done with some type of slimhole.

Spoerker, H.F., et al, "The World's First Multi-Year Slimhole Exploration Project - A Successful Partnership Between Operator and Contractor," SPE/IADC 29356 presented at the 1995 SPE/IADC Drilling Conference, Amsterdam, February 28-March 2, 1995

The authors discuss the results of a two-year program to drill exploratory slimholes in Venezuela. The two involved companies (both affiliates of PdVSA) invested in a rig specifically designed for slimhole drilling and continuous coring. The companies worked closely with the drilling contractor, Nabors Drilling Intl., Ltd. The authors explain problems and solutions that arose as the drilling project proceeded. The results of the project led the authors to conclude that "(p)urpose-built slimhole drilling rigs are capable of outperforming standard drilling equipment when regarded under the whole project cost." "Smaller locations, reduced mud/casing/cement volumes and faster rig moves justify the investment into specialized equipment for long-term drilling programs." In the paper, the authors note that (a)verage total-well savings range from 25 and 35 percent compared to standard full-size drilling equipment and underline the slimhole advantage when drilling exploratory wells in unknown areas." This drilling project involved environmentally sensitive locations and drilled section in tectonically active zones. Therefore, the authors' conclusions are applicable to a specific set of circumstances. However, the paper is a good reference for an operator considering slimhole drilling.

Hall, C.R., and Ramos, A.B., "Development and Evaluation of Slimhole Technology as a Method of Reducing Drilling Costs for Horizontal Wells," SPE 24610 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, DC, October 4-7, 1992

This paper reviews the advantages provided by slim hole wellbores compared to the known capabilities of using reduced hole and larger hole technology. It uses information gained from horizontal drilling operations in the Austin Chalk Formation in the Pearsall Field in South Texas. Various improvements in directional drilling equipment are discussed as to their impact on reduced hole/slim hole drilling. This paper also discusses the decision process which must be used to determine if a slim hole well is applicable. It concludes that slim hole drilling offers great opportunity for cost reduction in drilling operations, but requires interactive involvement from all areas associated with the well to prevent the limitations of a smaller wellbore from exceeding its benefits.

Randolph, S.B., and Jourdan, A.P., "Slimhole Continuous Coring and Drilling in Tertiary Sediments," SPE/IADC 21906 presented at the 1991 SPE/IADC Drilling Conference, Amsterdam, March 11-14, 1991

This early paper on slimhole drilling may prove useful. The authors provide a detailed discussion of coring and drilling 3 1/16 inch and 4 3/8 inch holes in soft sediments of the Texas Gulf Coast. The drilling project was conducted to demonstrate feasibility, and the project included testing of various bits, coring systems, drilling rates, and drilling fluids. The authors report on the pros and cons of each technique. The authors concluded that "slimhole continuous coring and drilling could be successfully conducted in soft sediments." This is a good background paper for operators considering slimhole drilling in soft sediment.

2.9 MULTILATERAL DRILLING AND COMPLETION

Multi-lateral drilling and completion can provide significant waste minimization benefits. This drilling technology reduces the number of necessary drilling sites and total footage drilled. This obviously can improve the economics of developing a field. But, waste minimization benefits are also derived, such as reduced drill cuttings and waste drilling fluid quantities, and other waste streams associated with drilling operations. Multilateral drilling was initially desired for offshore application, because it reduces platform size and weight. However, more recent papers demonstrate that multidirectional drilling and completion may be effectively applied in onshore projects. The following papers describe the application of multi-lateral well drilling and completion technology.

Owodunni, A., et al, "The Use of Multilateral Technology to Arrest Production Decline in a West-Texas Gas Field," SPE 84029 presented at the 2003 SPE Annual Technical Conference and Exhibition, Denver, CO, October 5-8, 2003

The authors provide an overview of the various classifications of multilateral well completions developed by the industry consortium, Technical Advancement for Multilaterals (TAML). They then thoroughly describe the process by which a multilateral development plan (using the appropriate TAML classification) was prepared for a mature field in West Texas. Regulatory constraints (e.g., well spacing and location), as well as economics, were primary issues. The authors provide a detailed discussion of the multilateral drilling and completion plan for one well and note that the plan must be "fit-for-purpose." They note the benefits realized by drilling the multilateral well (vs. two wells), including reduced drilling cost (about 20%), increased productivity, and maximized acreage. Waste minimization benefits included reduced rig footprint (i.e., one location vs. two locations), reducing drill cuttings, and reduced waste drilling mud. Interested operators will find this paper provides an excellent description of the successful drilling and completion of a multilateral well.

Hovda, S., et al, "World's First Application of a Multilateral System Combining a Cased and Cemented Junction with Fullbore Access to Both Laterals," SPE 36488 presented at the 71st SPE Annual Technical Conference, Denver, CO, October 8-9, 1996

The authors describe in much detail the planning and drilling of a multilateral well in the North Sea. The authors do not provide references, but it appears the described drilling project followed the system development and testing described in SPE 35545 (referenced below). This paper provides excellent detail regarding all operational aspects of the drilling project. It would be of most interest to a company's drilling engineers who are interested in multilateral drilling and completion. Unfortunately, the authors do not address the reduction of waste generation achieved in the project.

Longbottom, J.R., "Development and Testing of a Multi-Lateral System," SPE 35545 presented at the European Production Operations Conference, Stavanger, Norway, April 16-17, 1996

This paper is interesting in that the author describes a service company's development and testing of a multilateral system for drilling and completion. The company worked with an operator, who specified needs regarding the system. The author describes the testing of individual components (including composite pipe) and the subsequent testing of the system as a whole for tool compatibility. The paper provides a good overview of multidirectional drilling issues, such as addressing the need for mechanically connecting the lateral liner to the parent casing. The author states that actual field trials were ongoing, but did not elaborate. The waste minimization and environmental benefits of multidirectional drilling are cited.

2.10 PRODUCT SUBSTITUTION OPPORTUNITIES AT THE DRILL SITE

Additives for Differential Sticking ("Spotting Fluids")

Bland, R.G., et al, "Application of New Glycol/Resin Differential Sticking Preventative," SPE 24591 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, DC, October 4-7, 1992

This paper describes an oil-free polypropylene glycol/resin product designed to prevent differential sticking in water-based fluids. This product, a water-soluble polyglycol/asphalt (PGA) system, provides the permeability plugging advantages of traditional deformable resins over a broader temperature range as well as the lubricity of refined petroleum oils and traditional lubricants without the agglomeration and environmental problems. Laboratory results presented include particle size distribution, lubricity, "Cloud Point," toxicity, permeability plugging and HPHT dynamic filtration. Case histories documenting the use of PGA offshore in the Gulf of Mexico are included.

Pipe Dope

Stringfellow, W.D., and Jacobs, N.L., "Field Experiences With an Environmentally Acceptable Rotary-Shouldered Thread Compound," SPE 23920 presented at the 1992 IADC/SPE Drilling Conference, New Orleans, Louisiana, February 18-21, 1992

The authors summarize field experiences using a new technology rotary shouldered thread compound offered by their company, BOMAC b.v. (Finjaart, The Netherlands). The compound contains alumina-ceramic beads in a lithium-based grease. The authors correctly note that conventional thread compounds contain high percentages of heavy metal powder (e.g., lead) which pose an environmental liability. Their report on field tests and drilling experiences in several geographic areas concludes that the subject compound performs as well as conventional compounds, but does not create similar problems (e.g., toxicity and poor performance at high temperatures). Another advantage of the new compound is that it can be cleaned from pipe thread using warm water and biodegradable surfactant. Heavy-metal-based compounds typically require mineral spirits for removal.

The paper provides an overview of the application and general performance standards for rotary-shouldered pipe dope. They discuss the basis for changing to alternative compounds while meeting performance standards.

Ogasawara, M., et al, "Optimum Use of Environmentally Safe Compound Grease for Application of Casing and Tubing Connection Makeup," SPE 22555 presented at the 66th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Dallas, TX, October 6-9, 1991

Two "environmentally safe" greases were investigated for their water and gas tightness and anti-galling characteristics against API-spec pipe dope. Grease B is lead and zinc free while Grease C is lead free only. Fine grain graphite is added to the grease as a substitute for lead or zinc. The investigation revealed that lead free greases are not satisfactory for producing leak tight seals and generally do not satisfy the anti-galling standards specified by API. The authors conclude that further investigation is needed to develop a compound with the right grease, distribution of graphite, and selection of solid compound(s).

Since 1991, new and improved lead-free compounds may have been developed. Check with vendors prior to using leaded pipe dope.

Chemicals, Various

O'Neill, J.E., and Hill, D.G., "Reduction of Risk to the Marine Environment from Oilfield Chemicals – Balancing Environmental and Technical Needs," SPE 35946 presented at the International Conference on Health, Safety & Environment, New Orleans, LA, June 9-12, 1996

The authors describe Schlumberger Dowell's program to develop substitute products for surfactants, acid corrosion inhibitors, acid gelling agents, and brine viscosifiers in North Sea applications. It is important to note that the program was driven by strict chemical use guidelines established by North Sea area government. The authors emphasize that product substitution alone is not adequate – operators must also assess and improve the engineering processes to reduce waste and risk to the environment. Along that line, they note the success of "on-the-fly" mixing systems for well completion and stimulation fluids. With respect to product substitution, the authors describe the development of alternative formulations for the fluids listed above. In each instance, the company (in cooperation with chemical manufacturers/suppliers) successfully developed alternatives which were less toxic and provided performance equivalent or better than the original fluids. The authors do not address the commercial availability of the new products or the economics of the project.

Gas for Underbalanced Drilling

PTTC New Technology Summary, "Using Exhaust Gas for Underbalanced Drilling," *PTTC Network News* (2nd Quarter, 1998)

This article in the Petroleum Technology Transfer Council's newsletter summarizes a service offered by Unbalanced Drilling Systems Corp (UBDS) of Alberta, Canada, for using exhaust gas as a replacement for nitrogen or CO^2 in unbalanced drilling. The process is reported to be widely

used in Western Canada. According to the summary, well site installation of the exhaust gas collection and treatment equipment takes less than two hours. The exhaust gas is collected from the drill rig's propane fueled drive engines, cooled, chemically altered, and dehydrated prior to being fed to the compressors. To assure quality, the exhaust gas is monitored for temperature, pressure, oxygen content, effluent pH, and volume as it moves through the process and compression stages prior to injection. The summary does not indicate whether or not the system will use exhaust gases from other than propane-powered engines. The cost of using treated exhaust gas is claimed to be from one-half to one-fifth the cost of bottled nitrogen (the gas phase of unbalanced drilling can account for 25 to 50 percent of the total cost of drilling). The use of exhaust gas is an excellent example of recycling. It eliminates the exhaust gas an air emission.

2.11 RECYCLING DRILLING WASTES

Recycling Drilling Mud

Cannon, R.W., and Martin, D., "Reduction of Synthetic Based Fluid Discharges Offshore by the Use of Vertical Basket Centrifuges," SPE 66535 presented at the SPE/EPA Exploration and Production Environmental Conference, San Antonio, TX, February 26-28, 2001

The authors describe the use of vertical basket centrifuge systems to reduce the quantity of synthetic-based mud (SBM) from discharged cuttings. Although the reduction of discharged mud is the main goal, the process also provides for the recovery and reuse of SBM. The authors explain the various configurations for the vertical basket centrifuge system and the factors that affect its performance. The authors also describe the results of its use on 23 offshore wells. Of particular note, the system recovered 14,140 barrels of SBM (average 615 barrels per well). Based on an average SBM price of $200/bbl, a total savings of $2.83 million ($123,000 per well) was realized. This system was used offshore; however, there may be onshore application under certain circumstances (e.g., a sensitive environment).

Shaw, G.A., and Slater, B., "Removing Oil from Drill Cuttings - an Offshore Solution," SPE 19242/1 presented at the Offshore Europe 89, Aberdeen, September 5-8, 1989

This paper describes an oil-based cuttings cleaning fluid which has been developed and tested. The cleaning fluid can reduce the level of residual oil on the cuttings from greater than 20% v/v to less than 2% v/v. The cleaner, called K5T neither dissolves nor emulsifies the oil, but displaces it on the surface of the cuttings. Once the contaminating oil has been displaced, the cleaner and the oil separate under centrifugal force into two distinct phases. This allows the oil to be recycled back to the active mud pit and recovery of the cleaner for reuse. A multi-stage separation process is required to remove fines from both recovered phases. The waste minimization advantage of this process is the recycling of the oil into the OBM. No information was given on the amount of savings.

Recycling Water at a Drilling Site

McKay, H. et al, "Minimizing Drilling Fluid Waste Discharges While Drilling an Arctic Exploratory Well," SPE 21765 presented at the Western Regional Meeting, Long Beach, California, March 20-22, 1991.

The authors describe drilling fluid solids control and dewatering using a chemically-enhanced centrifuge. The impetus for implementing the process was strict Alaskan and federal (CWA) regulatory requirements (e.g., no liquids in pit). However, the paper provides yet another description of successful solids control/dewatering and water recycling.

Malachosky, et al, "Impact of Dewatering Technology on the Cost of Drilling-Waste Disposal," SPE 19528, *Journal of Petroleum Technology* (June 1991) 730736

Chemically enhanced centrifugation for solids removal is presented as a method to reduce volumes and disposal costs of drilling wastes. The authors use a well drilled in Kern County, California, to illustrate how the system saved $136,900 in waste disposal costs. The system consists of a series of centrifuges and flocculant injectors to remove fine solids that otherwise are not removed by the conventional solids control equipment (shaker, desander, desilter). After removal of the fine solids, the processed water is then reused in the mud system and the volume of waste requiring disposal is significantly reduced. This technique also reduces the volume of make-up water required.

Nordquist, D.G. and Faucher, M.S., "A Case History of Dewatering and Recycling Sump Drilling Mud on 141 Wells in the Midway Sunset Field, California," IADC/SPE 17246 presented at the 1988 IADC/SPE Drilling Conference, Dallas, Texas, February 28-March 2, 1988

The authors (of Sun E&P and Swaco) describe a solids control system similar to the system described in SPE 35914. However, in this instance the system was centrally located in a field with an ongoing in-fill drilling program. Rather than transport liquid drilling waste to a disposal facility (evidently as required by California regulations), the operator removed solids at the facility and recycled the clean fluid for use in other drilling fluid systems. The system saved a significant amount of dollars, but savings are calculated on reduced disposal costs which may not be imposed by other states' regulations. An operator in another state still may find such a system cost-effective.

2.12 WELL COMPLETION

Blast Furnace Slag Mud Converted to Cement as an Alternative

Numerous technical papers and articles have been published on the subject of converting blast furnace slag (BFS) and drilling mud to cement in wells. The authors of the papers have reached varying conclusions based on their study and testing of the process. In some instances, authors have concluded that the process provides a cement job that is at least equivalent to conventional Portland cement. Other authors note limitations to the process. Operators interested in using a BFS and mud mix for cementing should review all technical papers and other available information to determine if the process may be useful in their operation. The waste minimization achieved by successfully using a BFS mud mix for cementing is a reduction in the volume waste drilling mud.

The technical papers listed below (in chronological order) provide good discussions of the use of BFS mud for cementing. (More recent papers will be added as the Waste Minimization Program's review of the subject proceeds.)

Wu, D, et al, "Slag/Mud Mixtures Improve Cementing Operations in China," *Oil and Gas Journal* (December 23, 1996) 95-100

Sabins, F.L., et al, "Critical Evaluation of Blast Furnace Slag Mud Converted to Cement," IADC/SPE 35085 presented at the 1996 IADC/SPE Drilling Conference, New Orleans, LA, March 12-15 1996

Mueller, D.T., et al, "Portland Cement – Blast Furnace Slag Blends in Oilwell Cementing Applications," SPE 30513 presented at the SPE Annual Technical Conference & Exhibition, Dallas, TX, October 22-25, 1995

Sweatman, R.E., et al, "First High-Temperature Applications of Anti-Gas Migration Slag Cement and Settable Oil-Mud Removal Spacers in Deep South Texas Gas Wells," SPE 30512 presented at the SPE Annual Technical Conference & Exhibition, Dallas, TX, October 22-25, 1995

Daulton, D.J., et al, "Field Experience With Application of Blast Furnace Slag to the Drilling and Cementing Program in the Stratton Field, South Texas," SPE 29472 presented at the Production Operations Symposium, Oklahoma City, OK, April 2-4, 1995

Nahm, J.J., et al, "Interfacial Sealing Properties of Slag Mix (Mud-to-Cement Conversion Technology): Laboratory and Field Evaluation," SPE/IADC 29407 presented at the 1995 SPE/IADC Drilling Conference, Amsterdam, February 28-March 2, 1995

Saasen, A., et al, "The Use of Blast Furnace Slag in North Sea Cementing Applications," SPE 28821 presented at the European Petroleum Conference, London, U.K., October 25-27, 1994

Mueller, D.T., and Dickerson, J.P., "Blast Furnace Slag Technology: Features, Limitations, and Practical Applications," SPE 28475 presented at the SPE 69th Annual Technical Conference and Exhibition, New Orleans, LA, September 25-28, 1994

Leimkuhler, J.M., et al, "Downhole Performance Evaluation of Blast Furnace Slag-Based Cements: Onshore and Offshore Field Applications," SPE 28474 presented at the SPE 69th Annual Technical Conference and Exhibition, New Orleans, LA, September 25-28, 1994

Benge, O.G., and Webster, W.W., "Evaluation of Blast Furnace Slag Slurries for Oilfield Application," IADC/SPE 27449 presented at the 1994 IADC/SPE Drilling Conference, Dallas, TX, February 15-18, 1994

Schlemmer, R.P., et al, "Drilling Fluid Conversion: Selection and Use of Portland or Blast-Furnace Slag Cement," *SPE Drilling & Completion* (December 1994) 249-255 (This article is from SPE 26324 presented at the 1993 SPE Annual Technical Conference and Exhibition, Houston, TX, October 3-6, 1993.)

Nahm, J.J., et al, "Slag Mix Mud Conversion Cementing Technology: Reduction of Mud Disposal Volumes and Management of Rig-Site Drilling Wastes," SPE 25988 presented at the SPE/EPA Exploration & Production Environmental Conference, San Antonio, TX, March 7-10, 1993

Cowan, K.M., et al, "Conversion of Drilling Fluids to Cements With Blast Furnace Slag: Performance Properties and Applications for Well Cementing," SPE 24575 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, DC, October 4-7, 1992

Casing and Tubing

Day, J.B., et al, "New Makeup Method for API Connections," SPE 18697, *SPE Drilling Engineering* (September 1990) 233-238

This paper describes the development and field testing of a method for making up casing and tubing connections. Conventional methods (torque-only and torque-turn) were found to result in numerous leaks at connections, which resulted in well workovers and lost production. The new method, called torque-position, was found to essentially eliminate leaks in casing connections. The paper provides a detailed description of the method by which the makeup position is determined (critical parameters include size, weight, grade, plating type). The determined makeup position is painted on the pin end of the pipe. A proper, leak-free makeup is indicated by achieving a torque value within a determined minimum and maximum and the coupling face advancing into the position window. This makeup method was shown in numerous field applications to be effective in setting leak-free casing, and thereby preventing unnecessary well workovers and waste generation.

White, G.W., "Eliminating Galling of High-Alloy Tubular Threads By High-Energy Ion Deposition Process," SPE 12209, *Journal of Petroleum Technology* (August 1984) 1345-1351

The author describes the development of a high-energy ion coating process which has applications in the petroleum industry. As well as significantly improving tubular connections, the technology can reduce stuffing box leaks when used to treat polished rods. Similarly, it can extend the life of a valve stem and packing. The coating reduces galling and/or friction wear between surfaces. This process has been field-tested and has provided demonstrable results.

Cementing

Sørgård, E., and Villar, J.P., "Reducing the Environmental Impact by Replacing Chemistry with Physics," SPE 66551 presented at the SPE/EPA Exploration and Production Environmental Conference, San Antonio, TX, February 26-28, 2001

The authors describe the use of particle size distribution (PSD) in dry cement to control cement slurry properties. PSD is combined with adjustment of water/cement ratio and use of specific chemicals to achieve gas tightness to reduce or eliminate the need for many conventional chemical additives. PSD is similar to sizing a gravel pack in that the PSD optimizes particle bridging to achieve fluid loss control. In addition, PSD imparts high compressive strength development. The benefit gained in the authors' example (which is specific to the North Sea and colder sea floor temperatures) was a significant reduction of the chemicals used in the cement slurry. However, this technique may be a feasible waste minimization option in other areas, including onshore. Any reduction in the use of chemical additives reduces the potential for chemical waste generation and reduces the contaminant concentrations in any subsequent wastes generated by the operation.

McCalmont, et al, "Lightweight Cementing Program Increases Profit from Kansas Oil Field," *Oil and Gas Journal* (June 29, 1992)

This paper discusses a new, lightweight one-stage cement job that achieved an improved cement bond across a permeable oil/water sand in a Kansas field. The one-stage job was developed to overcome poor cement bonding results with the conventional two-stage method. Poor cement bonding across the permeable oil/water sand allowed excessive water production and in some cases prevented oil production. Although intended as a means to increase oil production, the method could be used as a waste minimization technique for reducing water production from permeable sands.

Mixing Fracturing Fluids and Cement On-The Fly

Terracina, J., et al, "Fracturing Fluid System Concentrate Provides Flexibility and Eliminates Waste," SPE 66534 presented at the SPE/EPA Exploration and Production Environmental Conference, San Antonio, TX, February 26-28, 2001

This paper by authors from Halliburton briefly describes a fracturing fluid system concentrate which may be mixed on-the-fly. The concentrate may be mixed with either fresh water or seawater and is stable for long periods of time, so can be returned or used at another location if necessary. The benefits of the concentrate and mixing on-the-fly are reduced waste generation and flexibility in designing hydraulic fracturing treatments.

Rae, P., and Johnston, N., "Liquid Cement Premix for Improved Abandonment and Workover Operations," SPE 36477 presented at the Annual Technical Conference and Exhibition, Denver, Colorado, October 6-9, 1996

Rae, P., and Johnston, N., "Liquid Cement Premix Introduces New Solutions to Conventional Cementing Problems," SPE 35086 presented at the IADC/SPE Drilling Conference, New Orleans, Louisiana, March 12-15, 1996

In these two papers, the authors describe the development of a liquid cement premix (LCP) with multiple uses and long-term storage capabilities. The LCP can be prepared using standard oilwell cements and will not set until an activator is added. One advantage of LCP is the ability to mix on-the-fly with activator as the cementing job proceeds. The mixing of liquids allows more precise and responsive density control (e.g., cement density can be adjusted on-the-fly). By mixing LCP on-the-fly, thus avoiding the problems associated with mixing dry cement powder and water, the waste of raw materials and generation of unused cement is minimized. The authors believe the use of LCP is initially best suited for cementing jobs that are small (e.g., plugging, coiled tubing) and cement jobs in remote areas. But, LCP should also be advantageous in large volume cementing jobs. The LCP system requires less space and operating personnel than conventional systems. The authors claim that these advantages can reduce an operator's cementing costs. Direct savings to the operator can result from reduction in costs of personnel, equipment, mobilization, transport, installation and material wastage.

O'Neill, J.E., and Hill, D.G., "Reduction of Risk to the Marine Environment from Oilfield Chemicals – Balancing Environmental and Technical Needs," SPE 35946 presented at the International Conference on Health, Safety & Environment, New Orleans, Louisiana, June 9-12, 1996

The authors describe Schlumberger Dowell's program to develop substitute products for surfactants, acid corrosion inhibitors, acid gelling agents, and brine viscosifiers in North Sea applications. The authors also emphasize that product substitution alone is not adequate – operators must also assess and improve the engineering processes to reduce waste and risk to the

environment. Along that line, they note the success of "on-the-fly" mixing systems for well completion and stimulation fluids.

Allen, T.E., "Pregel Blender Prototype Designed to Reduce Cost and Environmental Problems," SPE 27708 presented at the 1994 SPE Permian Basin Oil and Gas Recovery Conference, Midland, TX, March 16-18, 1994

The author describes the design of a blending unit for on-the-fly mixing of gels for fracturing jobs. An advantage of the described mixing system is that a liquid gel concentrate is not necessary, especially using diesel. The author provides a fairly detailed description of each system component and operation.

Chang, D.J., et al, "Wellsite Mixing Minimizes the Environmental Impact and Reduces Costs During Pumping Operation," SPE 27142 presented at the Second International Conference on Health, Safety & Environment in Oil & Gas Exploration & Production, Jakarta, Indonesia, January 25-27, 1994

The authors, of Dowell Schlumberger, describe two on-the-fly mixing systems: one for frac jobs and one for cementing. They provide an example of an actual application for each system and compare the waste generation and raw material needs for each job with the conventional frac and cementing procedures. In each case waste is minimized significantly – over 90%, mainly due to no dead volume of pre-mixed fluid in tanks. Excess raw materials are used for other well treatments. The need for drums was eliminated, instead using reusable tote tanks, which eliminated container waste. Because, the systems are self-contained, the potential for spills is reduced. The authors indicate that the use of the systems reduces costs considerably from the costs associated with use of pre-mixed batches.

Thompson, J.E., et al, "New Continuous-Mix Process for Gelling Anhydrous Methanol Minimizes Hazards," SPE 22800 presented at the 66th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Dallas, TX, October 6-9, 1991

A procedure for mixing fracturing (frac) fluids ""on-the-fly"" is presented. The continuous mix process effectively prepares methanol-based frac fluids for injection. In this process, the frac fluid quality can be monitored and adjusted as injection takes place. The continuous mix process offers several advantages over the conventional ""batch mix"" process: 1) extensive circulation (blending) of the flammable methanol frac fluid to achieve proper density is eliminated (improved safety and more efficient operation), 2) the volume of waste frac fluid is minimized to that left in the continuous mix blending equipment (none left in frac tanks to prevent pump cavitation). This paper includes a case history of field application which demonstrates the procedures' effectiveness.

Slim Hole Completions

See "Drilling Slim Holes" in this section.

Using Coiled Tubing

See "Drilling With Coiled Tubing" in this section.

Using A Snubbing Unit

See "Drilling With A Snubbing Unit" in this section.

SECTION 3

CRUDE OIL AND NATURAL GAS PRODUCTION OPERATIONS

Many oil and gas wastes generated in crude oil and natural gas production operations are exempted from classification as hazardous wastes. However, an operator may still obtain benefits from implementing waste minimization techniques. Numerous effective waste minimization opportunities exist, as evidenced by the technical papers and articles referenced below. In particular, many operators have developed operating procedures and techniques to reduce relatively high-volume wastes such as produced water and workover wastes. Another area which operators have addressed is techniques to reduce air emissions by improving emissions control and equipment operating efficiency (e.g., internal combustion engines). This section provides numerous references which may provide useful information to operators interested in minimizing waste generated by their production operations.

This section provides references to technical papers and articles which address the following:

Air Emissions Reduction

- General
- Volatile Organic Emissions
- Natural Gas
- Carbon Dioxide

Artificial Lift Alternatives

- Progressing Cavity Pumps
- Electric Submersible Pumps
- Plunger Lift
- Other

Automation of Production Operations (e.g., SCADA Systems)

Chemical Inventory and Use

Hydrogen Sulfide and Corrosion Control

Erosion Control for Flowlines

Crude Oil Reclamation and Improved Oil/Water Separation

Electric Power Efficiency at Production Sites

General

Rod Pump Efficiency

Produced Water

General

Formation Treatment to Reduce Water Production

Completion Techniques to Reduce Water Production

Downhole Oil, Gas, and Water Separation

Treating Produced Water To Reduce Associated Waste

Product Substitution in Production Operations

Recycling Production Wastes

Various Wastes

Produced Water

Brine Completion Fluids

Rod-Pumps and Tubing

Well Production and Stimulation

Using Coiled Tubing

Slim Hole Completions

Scale and NORM Control

Sand Control

Paraffin Control

Hydrate Inhibition

3.1 AIR EMISSIONS REDUCTION

General

Ritter, K., et al, "Application of the API Compendium To Examine Potential Emission Reduction Opportunities for Upstream Operations," SPE 80576 presented at the SPE/EPA/DOE Exploration and Production Environmental Conference, San Antonio, TX, March 10-12, 2003

This paper discusses the API's development of compendium of calculation techniques and emission factors that can be useful for developing greenhouse gas (particularly CO_2 and methane) emissions inventories. The paper also presents several emission reduction opportunities which have been successfully implemented by E&P companies.

(Note that several of the reduction opportunities are from the EPA's Natural Gas Star Program. Natural Gas Star Program technical support documents are available on their web site at http://www.epa.gov/gasstar/.)

Volatile Organic Emissions

Goodyear, M.A., et al, "Vapor Recovery of Natural Gas Using Non-Mechanical Technology," SPE 80599 presented at the SPE/EPA/DOE Exploration and Production Environmental Conference, San Antonio, TX, March 10-12, 2003

The authors describe the design and development of a vapor recovery system for crude oil and condensate tanks. The system uses high pressure gas as the motive gas in a venturi (eductor). The venturi draws gases from the tanks. The venturi discharge, at an intermediate pressure, may be directed to a compressor suction, low-pressure separator, fuel gas system, or flare. The authors describe how the system was designed and configured specifically for a South Texas oil and gas production facility. The cost of installation was about $100,000 with payback in less than four months (based on value of recovered gases). The benefit, as the paper title suggests, is that the system uses no moving part; therefore, it is more efficient and easier to operate and maintain. The system provides waste minimization benefits by greatly reducing air emissions, such as volatile organics and methane. Note that in certain cases, a state will have regulatory requirements to control such emissions; therefore, this system may also help with regulatory compliance.

Note: This vapor recovery unit is described in detail in the U.S. EPA's "Environmental Technology Verification Report, Environmental Vapor Recovery Unit (EVRU)" by COMM Engineering, USA, SRI/USEPA-ghg-vr-19 (September 2002). The report is available on the EPA web site at: http://www.epa.gov/etv/pdfs/vrvs/03_vr_comm.pdf.

Webb, W.G., "Vapor Jet System: An Alternative Vapor Recovery Method," SPE 25942 presented at the SPE/EPA Exploration & Production Environmental Conference, San Antonio, Texas, March 7-10, 1993

The author describes a patented vapor jet VOC (volatile organic compound) recovery system that is an economical, low-maintenance alternate to conventional VOC recovery. The system can economically recover low volumes of hydrocarbon vapors from an oil production facility's crude oil and produced water storage tanks. The system uses a pressurized stream of produced water as the operating medium in a jet pump (also known as a venturi eductor or ejector) where it entrains the near atmospheric pressure tank vapors (VOCs). The Water and VOCs are then returned to the facility's low pressure system for separation, recovery, and sale. The separated water is returned to the water tank. The components of the vapor jet system are an electrically driven centrifugal water pump, the jet pump, and the necessary piping. At the time the paper was written, the cost to purchase and install the system at a facility of two to four tanks was $10,000 to $15,000.

Also see a case study of the successful application of the vapor jet system in the September 2000 Petroleum Technology Supplement on the *World Oil*, Petroleum Technology web page at http://www.worldoil.com/Magazine/MAGAZINE_DETAIL.asp?ART_ID=2358&MONTH_YEAR=Sep-2000. (Troy Palmer, T. et al, "Reliable, low cost vapor recovery system saves money while helping the environment.")

Natural Gas

Newsom, V.L., Determination of Methane Emissions From Crude Oil Stock Tanks," SPE 37930 presented at the 1997 SPE/EPA Exploration and Production Environmental Conference, Dallas, TX, March 3-5, 1997

This paper provides a brief description of the development of "APITANK," a model for calculating the total hazardous air pollutants, volatile organic pollutants, and methane emissions from crude oil and condensate stock tanks. APITANK is stated to be an easy to use and reliable method. Using APITANK, an operator can determine the need and economic feasibility of installing a tank vapor recovery system and applicability of regulatory requirements for emissions monitoring and control.

Paz, R. et al, "Low Pressure Gs Gathering System: Environmental Solution for Hydrocarbon Emissions in Venezuela," Proceedings of the 4th International Petroleum Environmental Conference, San Antonio, TX September 9-12, 1997

This paper addresses a company's solution to reducing vented natural gas on rod-pumped oil wells. The authors describe Maraven S.A.'s field project to identify the optimum system for collecting and compressing natural gas from well annuli. As well as desiring the environmental benefit of reducing emissions, the operator wished to improve production rates by reducing backpressure due to gas. The authors describe field application of walking beam mounted

compressors and, separately, the use of a centralized reciprocating compressor. They explain how the centralized compressor proved to be the most effective system, even though the initial investment was incrementally higher. Even so, the project proved economical. This paper provides a very good example of successful, cost-effective collection and use of oil well gas.

This paper is available at http://ipec.utulsa.edu/.

Peavy, M.A. and Braun, J.E., "Control of Waste Gas From a Thermal EOR Operation," SPE 21766 printed in *Journal of Petroleum Technology* (June 1991) 656-661.

The authors describe a casing vapor recovery system (CVRS) used to control emissions from the Midway Sunset Field in California. The field produces heavy oil (about 10^o API gravity) using steam for enhanced recovery. The CVRS recovered 550 bpd (from 934 wells) of light crude oil and hydrogen sulfide, which were previously vented to the atmosphere. Remaining waste gases were incinerated and scrubbed of SO_2. An additional benefit of the system was improved production due to lowered casing pressures. The authors provide a detailed description of the CVRS and its operation and note that payout for the capital investment to install the system was about 5 years. Although steam-flooding for EOR is not all that common in Texas, this paper provides a description of an effective system for recovering gases from producing well casings. (Note: This paper was first presented at the 1991 SPE Western Regional Meeting, Long Beach, CA, March 20-22, 1991.)

Carbon Dioxide

Rawn-Schatzinger, V., "CO_2 Recovery from Flue Gas for use in EOR," *Eye on Environment*, Vol.4 No. 1, U.S. Department of Energy (January 1999) 6-7

This article describes a system designed by Mitsubishi Heavy Industries of Japan which will recover 99.9% pure CO_2 from flue gas. CO_2 recovery from boiler flue gas has been used in the carbonated beverage industry for years, but the production of CO_2 on a large scale was not economically feasible and did not meet the needs for nationwide clean air standards. Mitsubishi started development of an improved CO_2 recovery system in 1990 and a pilot plant was built in 1991.

The CO_2 generated by the flue gas recovery method has potential in the United States for use in enhanced oil recovery (EOR) projects using CO_2. Costs of using CO_2 could be significantly reduced by recovering CO_2 at power plants (e.g., a 50 megawatt local generation plant) close to a the CO_2 EOR project. Not only is the cost of CO_2 generation less expensive, but the cost of transportation is dramatically reduced, particularly in places where no existing pipelines have been established. A primary advantage cited by the article is the cost to generate CO_2 from flue gas. In 1998, flue gas CO_2 cost \$0.76/MSCF, whereas gas turbine generation of CO_2 cost \$1.20/MSCF.

This article is available at http://www.npto.doe.gov/EOE/Jan99/page6.html. Also, this subject is addressed in the following reference:

Iijima, M., "A Feasible New Flue Gas CO2 Recovery Technology for Enhanced Oil Recovery," SPE 39686 presented at the 1998 SPE/DOE Improved Oil Recovery Symposium, Tulsa, Oklahoma, April 19-22, 1998

3.2 ARTIFICIAL LIFT ALTERNATIVES

Progressing Cavity Pumps

Progressing cavity pumps (PCPs) are widely used for artificial lift. PCPs are advantageous for lifting heavy crude oil, oil with higher sand content, and high-volume, high-water cut oil. On the surface PCPs use only an electric motor on a drivehead; therefore, waste generation is minimized and maintenance is simplified. Also, the capital investment to install a PCP system is relatively low. PCPs have limitations, such as the incompatibility of some elastomers with volatile compounds in some crude oils (e.g., benzene) or H_2S. However, PCP technology is continually advancing, with improved pump materials being developed (e.g., stator elastomers described in following papers). The following papers and articles provide a good overview of PCPs and their applications.

Oglesby, K.D., et al, "Fourteen Years of Progressing Cavity Pumps in a Southern Oklahoma Field," SPE 80919 presented at the SPE Production and Operations Symposium, Oklahoma City, OK, March 23-25, 2003

The authors report on the experiences and lessons learned from using progressing cavity pumps (PCPs) for artificial lift in a relatively shallow (about 2,100 feet) oil field with a high water cut. The results of the use of PCPs have been low capital costs, low repair costs, and high electrical efficiency; all of which have reduced daily costs. The authors state that PCPs were installed because the increasing water cut and associated lifting costs using beam pumps and electrical submersible pumps had increased costs (e.g., electrical costs for PCPs are 5% and 35% less, respectively). They explain the evolution of the PCP systems in the field and note problems and pitfalls with the PCP systems, such as stator elastomer swelling and rods parting at the drivehead. This paper provides a good example of the successful application of PCPs for artificial lift.

R&M Energy Systems, "Progressing Cavity (PC) Pump Design Optimization for Abrasive Applications," SPE 37455 presented at the 1997 SPE Production Operations Symposium, Oklahoma City, OK, March 9-11, 1997

This paper provides a good explanation of the PCP principles and operating parameters. The paper explains the optimum PCP design to minimize pump abrasion when pumping sand-laden crude oil.

Mills, R.A.R., and Gaymard, R., "New Applications for Wellbore Progressing Cavity Pumps," SPE 35541 presented at the International Petroleum Conference & Exhibition of Mexico, Villahermosa, Mexico, March 5-7, 1996

The authors provide a thorough overview of the "state-of-the-art" of PCPs in 1996. They describe the various types of rubber-based elastomers and their respective features and applications (e.g., the best elastomer for crude oil with higher volatile compound concentrations). Needed advances in elastomer composition and critical properties are noted. The authors also describe the considerations necessary regarding driveheads and associated torque in rod strings.

Wiltse, D.J., and Weir, B.A., "Eliminating Sucker Rod Couplings Can Reduce Progressing Cavity Pump Operating Costs," SPE 30275 presented at the International Heavy Oil Symposium, Calgary, Alberta, Canada, June 19-21, 1995

The authors explain how the use of a continuous sucker rod string improves flow and, thus, reduces the differential pressure of the PCP. The paper provides a discussion of the authors use of computer software to model the effects of continuous rod strings versus convention coupled rod strings. The modeling showed a significant decrease in drivehead horsepower requirements, which reduces electrical power consumption. The authors also note that the PCP and rod string would operate longer thus reducing maintenance costs. The paper does not present results of actual field application.

Dunn, L.J., et al, "Progressive Cavity Pumping System Applications in Heavy Oil Production," SPE 30271 presented at the 1995 International Heavy Oil Symposium, Calgary, Alberta, June 19-21, 1995

The authors provide a thorough discussion of the design and use of progressive cavity (PC) pumping in heavy oil production. The authors state, "The functional design of PC pumps facilitates the handling of viscous and abrasive multiphase fluids, and the lower capital and operating costs of these pumping systems makes them attractive for marginally economic operations." The authors discuss the advantages and disadvantages of PC pumping. With respect to reducing waste generation PC pumping is more efficient and reduces the need for frequent repairs and workovers that can occur with the conventional rod pump. Therefore, waste generation associated with power consumption and well servicing is minimized. To provide the reader with thorough understanding of PC pump system design, the authors provide a detailed discussion of design considerations such as flow losses, sand production, rod string and tubing wear, low bottomhole pressure, power transmission/control, and pump selection, sizing and reuse. The authors note that computer models, such as *PC-Pump*, have been developed to assist in system design and evaluation. This paper is an excellent resource for operators producing heavy oil (e.g., less than 20^{o} API).

Saveth, K.J., "Field Study of Efficiencies Between Progressing Cavity, Reciprocating, and Electric Submersible Pumps," SPE 25448 presented at the Production Operations Symposium, Oklahoma City, OK, March 21-23, 1993

The authors presents the results of a field test to compare the efficiency of progressing cavity pumps, reciprocating (rod) pumps, and electric submersible pumps (ESPs). Six high water cut oil wells with similar completions and production were used for the study. The wells were relatively shallow with pump depths from 2,000 feet to 2,400 feet. The author notes that the six wells did not necessarily have optimum settings for the method of artificial lift in use. The results of the study showed that PCPs were much more efficient and reduce both capital and operating costs. The PCP had an average efficiency of 76%, whereas the rod-pump and ESP had about 35% average efficiency.

Wright, D.W., and Adair, R.L., Progressive Cavity Pumps Deliver Highest Mechanical Efficiency/Lowest Operating Cost in Mature Permian Basin Waterflood," SPE 25417 presented at the Production Operations Symposium, Oklahoma City, OK, March 21-23, 1993

The authors describe a filed test study to evaluate the performance of progressing cavity pumps (PCPs) in mature waterflood producing wells. The wells produced from depths of 3,800 feet to 5,000 feet and at rates ranging from 500 barrels per day to 1,000 barrels per day. Increased water production had necessitated the need for increased lift capacity, which exceeded beam-pump potential. The study concluded that PCPs were the most cost-effective lift system for the circumstances. This paper is a good case history for the success of PCP lift systems.

Saveth, K.J., and Klein, S.T., "The Progressing Cavity Pump: Principle and Capabilities," SPE 18873 presented at the SPE Production Operations Symposium, Oklahoma City, OK, March 13-14, 1989

The authors describe PCPs and compare calculated efficiencies for a PCP, electrical submersible pump, and a plunger pump system for the same specified well conditions. The PCP was indicated to be much more efficient (*see* SPE 25448 above, which presents proof in the field).

Electric Submersible Pumps

Galles, D.J., and Larson, J.B., "Optimized Electric Submersible Pumping to Extend Economic Oil Production in a High Water Cut Environment," SPE 29505 presented at the Production Operations Symposium, Oklahoma City, Oklahoma, April 2-4, 1995

The authors describe modifications made to electrical submersible pumping systems (ESPs) to achieve reduced power consumption through improved efficiency. The project was conducted at a high water cut oil field in Utah (85 BOPD and 35,100 BWPD from four wells). The systems were improved by thoroughly researching optimized equipment configurations, which included a

teardown analysis of previous failed equipment and pump run lives. A description of the selected ESPs and their configuration is provided. The authors state that the annualized power cost savings were $26,700 per year and projected incremental oil recovery from reduced lease operating expenses to be 120,000 STB. This paper clearly demonstrates the economic advantage of optimizing and reducing electric power usage in a producing oil field. (Note that the produced water was relatively fresh and, after treatment, was used as a source of agricultural irrigation water. Therefore, produced water disposal costs were minimized and did not impact field economics to the same degree as conventional disposal.)

Plunger Lift

Plunger lift is an attractive option for other artificial lift systems. Operators should assess their producing wells to determine if plunger lift is feasible. Plunger lift is primarily advantageous for high gas-liquid ratio wells. But, plunger lift does not require an outside source of energy for the lifting, and therefore will improve the economics of certain producing wells. Plunger lift is not truly an artificial lift mechanism, since reservoir energy is the driver. But, plunger lift may be augmented with an external source of gas if necessary. Plunger lift is a good waste minimization option, because it eliminates the surface equipment of other systems which generate wastes, such as used lube oil. Plunger lift also reduces demand for electrical power, which in turn reduces emissions associated with power generation. The following papers offer good discussions of plunger lift design and operation.

Baruzzi, J.O.A., and Alhanati, F.J.S., "Optimum Plunger Lift Operation," SPE 29455 presented at the Production Operations Symposium, Oklahoma City, OK, April 2-4, 1995

The authors provide a detailed discussion of plunger lift operating parameters. They describe a method to predict when it is possible to have liquid accumulation only in the tubing during the buildup period and to predict the minimum gas-liquid ratio (GLR) to reach that desirable condition. The authors then offer practical recommendations on how to obtain optimal conditions for a typical plunger lift installation. Plunger lift has limited application, primarily as a lift option for high GLR wells. The advantage of plunger lift is that it requires no input energy and effectively controls paraffin and scale accumulation in the tubing. The authors note the main disadvantage may be a greater need for continuous monitoring. Controllers are available (and likely improved since this paper was presented) which may relieve some need for system monitoring by field staff.

Morrow, S.J., and Rogers, J.R., Jr., "Increasing Production Using Microprocessors and Tracking Plunger-Lift Velocity," SPE 24296 presented at the SPE Mid-Continent Gas Symposium, Amarillo, TX, April 13-14, 1992

The authors, of Ferguson Beauregard, discuss the use of plunger velocity to establish operating cycles for oil and gas wells in conjunction with the use of microprocessor controllers. They offer results of field applications which resulted in increased plunger lift efficiency and production.

The authors note that plunger lift may be applied to gas well dewatering, as well as for high GLR wells.

Chacin, J., et al, "Modeling and Optimization of Plunger Lift Assisted Intermittent Gas Lift Installations," SPE 23683, *SPE Advanced Technology Series*, Vol. 2, No. 1 (March 1994) 25-33

This paper offers a model for designing a plunger lift system to assist intermittent gas lift. The authors describe the model, which can be used to obtain an optimum design, considering both gas consumption costs and crude oil recovery. The main benefits of plunger lift assistance are decreased gas injection requirements and reduced fallback (due to the presence of the plunger).

Marcano, L., and Chacin, J., "Mechanistic Design of Conventional Plunger Lift Installation," SPE 23682-P, *SPE Advanced Technology Series*, Vol. 2, No. 1 (March 1994) 15-24

The authors present the results of work to develop a comprehensive mechanistic model of conventional plunger lift installations that includes all relevant stages of the production cycle. The developed model was used to construct a computer program to effectively design and troubleshoot conventional plunger lift installations.

Narvaez, C., and Ferrer, A.A., "Prevention of Paraffin Well Plugging by Plunger-Lift Use," SPE 21640 presented at the Production Operations Symposium, Oklahoma City, OK, April 7-9, 1991

This paper describes the use of plunger lift systems for the control of paraffin deposition in flowing and gas lift wells. The expansion and cooling of injected gases is a primary cause of paraffin deposition. The design of the plunger lift installation is well-specific, and is described by the authors for different examples. The authors discuss the application of plunger lift for paraffin control in several wells, and in each instance production rates were improved. An important benefit of the plunger lift system was the significant reduction of well treatments (e.g., mechanical scraping and hot-oiling) to remove paraffin from tubing, which resulted in more efficient and cost-effective production operations and waste minimization.

Crow, R.W., "Electronic Controller for the Optimization of Plunger-Lift Wells," SPE 21290 presented at the SPE Eastern Regional Meeting, Columbus, OH, October 31-November 2, 1990

The author, of Otis Engineering Corp., describes the design and operation of an electronic microprocessor for plunger lift wells. The author states that using the microprocessor to interface with a sensor installed at the wellhead, a controller can constantly monitor plunger

arrivals and automatically adjusts plunger operation to maximize production. The paper describes the controller's ;logic and function and presents case histories of its use. The author states that this controller does not require continuous operator adjustment for optimization which is required of the electronic controllers based on time and/or pressure.

Beauregard, E., and Morrow, S., "New and Unusual Applications for Plunger Lift System," SPE 18868 presented at the SPE Production Operations Symposium, Oklahoma City, OK, March 13-14, 1989

The authors advocate the use of plunger lift systems for several applications. They provide case histories of the successful use of plunger lift for low-pressure reservoirs, high GLR wells, wells with no tubing (i.e., a "casing plunger"), and paraffin control in dual-zone wells and deviated gas lift wells. Of particular interest, the authors describe a field in Wyoming that was kept on production by plunger lift at the point it became uneconomic using rod pumps.

Other

Fox, B., and Allen, G., "Alternative artificial lift system improves well productivity," *World Oil*, Case Studies - Petroleum Technology Digest (May 2000)

This article discusses the installation of the BORS Lift (see the following reference) on five wells in an Oklahoma oil field. The article, written by the president of the operating company, describes the success of the project. According to the article, the five stripper wells increased production from a total of seven barrels per day to 23 barrels per day and practically eliminated water production. Operating costs were reduced by $2,700 per month and power costs were reduced by $265 per month. The operator leased the BORS Lift units ($2,080 per month) with an option to purchase. Therefore, it appears the installation of the lift system was economically successful. The author also noted that the BORS Lift is limited to a well depth of 2,500 feet and does not capture casing head gas, though development is underway to overcome those limitations.

This paper is available at www.worldoil.com. See page viii for tips on accessing *World Oil*, Case Studies.

Allen, G, "Production of Oil Without Salt Water," Proceedings of the 6th International Petroleum Environmental Conference, Houston, TX, November 16-18, 1999

This paper briefly describes an artificial lift design that uses a computer driven lifting system. The correct computer program for lifting water-free oil is reliant on accurate reservoir data. The system is called the BORS Lift (Balanced Oil Recovery System Lift), and at the time of the papers presentation it had limited application. The author states the reservoir must be driven by natural gas, solution gas or a combination of both. The basis for the system is that the oil and water columns in the well will achieve a balanced state. The programming of the computer

controls the BORS Lift such that that balance is maintained and only oil is produced. A hose lifted by a strap delivers oil to the surface. The paper includes a description of the control system and lift motor. The BORS Lift appears to be intended primarily for stripper wells. The author notes that the system uses no rods, tubing or other downhole equipment, and is more energy efficient, thus reduces operating costs.

3.3 AUTOMATION OF PRODUCTION OPERATIONS (E.G., SCADA SYSTEMS)

Many operators have found that automating operations can greatly improve efficiency. The Supervisory Control and Data Acquisition (SCADA) systems are a good example of automation. Automation using a SCADA system can help minimize waste generation by reducing equipment failures, which in turn reduce maintenance and well workover requirements. It also can reduce incidences of spills and leaks. The following papers provide examples of how such systems have been implemented and the associated benefits which were realized.

Dunham, C.L., "Production Automation in the 21st Century: Opportunities for Production Optimization and Remote Unattended Operations," SPE 79390, *Journal of Petroleum Technology* (July 2003) 68-73

This paper's purpose "is to challenge management and staff in operating companies, service and supply companies, and others to understand and appreciate the significant benefits that can be realized with effective implementation and use of production automation. The author summarizes the business objectives that can be achieved, discusses specific operational and economical benefits, and briefly highlights new technologies.

Giangiacomo, L.A., and Hill, D.R., "Optimizing Well Efficiency With Smart Fluid-Level Controller Technology," SPE 52210 presented at the 1999 SPE Mid-Continent Operations Symposium, Oklahoma City, OK, March 28-31, 1999

The authors discuss the ongoing development of an improved fluid level controller, which can greatly improve the operating efficiency of rod-pumped wells (and wells with progressing cavity and electrical submersible pumps). The paper provides a through overview of well optimization using timers, pump-off controllers and echometers. The authors discuss how the new fluid level controller may be used in conjunction with remote telemetry to maximize well efficiency. The described fluid level controller will allow a well to avoid fluid pounding and pump at maximum efficiency almost at all times. Benefits include reduced pump wear and maintenance requirements, thus reducing waste generation. As well, the profitability of the well is improved.

Luppens, J.C., "Practical Automation for Mature Producing Areas," SPE 26591 presented at the 68th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Houston, TX, October 3-6, 1993

This paper provides a case history of the successful application of SCADA systems in several producing fields in Oklahoma. The authors provide a thorough overview of the process from acquisition of the system to implementation. The systems resulted in significant benefits, including: reduced downtime (up to 83%); reduced surface maintenance costs on beam-pumped wells (average of 40%); reduced well workover costs (17% to 40%); production increases up to 30%; and significantly reduced spills and leaks. The authors also discuss the projects economics, which showed the SCADA systems to provide an very good return of investment and annual rate of return.

3.4 CHEMICAL INVENTORY AND USE

Brandon, D.M, et al, "Biocide and Corrosion Inhibition Use in the Oil and Gas Industry: Effectiveness and Potential Environmental Impacts," SPE 29735 presented at the SPE/EPA Exploration & Production Environmental Conference, Houston, TX, March 27-29, 1995

This paper discusses various treatment chemicals used in the natural gas industry. Treatment chemicals used as biocides and corrosion inhibitors are specifically addressed. The paper discusses the source of microbes and corrosion. Several case histories are presented for the use of certain treatment chemicals. Each case history includes an assessment of the environmental impact of the chemical. This paper may help in identifying effective treatment chemicals that are less toxic and reduce potential environmental impact.

Caudle, D.D., and Bansal, K.M., "Environmental Considerations in Production Chemical Usage," SPE 26010 presented at the SPE/EPA Exploration & Production Environmental Conference, San Antonio, TX, March 7-10, 1993

This paper examines a number of issues which impact the amount of chemical used and the limits on the minimization of its use. These issues include: attitudes towards chemical usage; process limitations; physical/chemical behavior of the chemicals; and interactions with other chemicals in the system. Wastes from the production treating chemicals are also discussed in this paper. A total system approach is proposed to minimize the chemical usage in production operations. Source reduction options for several chemical applications are provided.

Brost, D.F., et al, "Optical Methods for Monitoring Treating Chemicals in Oilfield Water Systems," SPE 22781 presented at the 66th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Dallas, TX, October 6-9, 1991

This paper presents the development and application of spectroscopic (UV absorption) methods of analysis for the determination of the concentrations of treating chemicals in oil field water

systems. Two systems are discussed: a xenon flash photometer (XFP) and short-wave ultraviolet spectroscopy. The discussion of the XFP development includes aspects of instrumental design and autocalibration methodology, performance evaluations based on laboratory studies, and the instrument's ability to monitor a quaternary amine corrosion inhibitor in an oil field water system (i.e., field application). Spectroscopic analyses were performed under actual field conditions, without dilution or sample pretreatment, and results were compared with those obtained with conventional univariate calibration. The conclusion drawn from this work was that the XFP and spectroscopic methods can be used for the on-line monitoring of multiple treating chemicals. As pointed out by the authors, these methods, used on-line, can make it much easier to maintain chemical dosages at prescribed levels, without sampling or operator intervention. The advantages offered include the prevention of formation or well completion equipment damage due to improper chemical dosage, feed-back control or variable speed chemical pumps, and minimization of the volume of treatment chemicals used.

3.5 HYDROGEN SULFIDE AND CORROSION CONTROL

Also *see* "Corrosion Protection" in Section 6.

Williams, J.M., "Getting Reliable On-Site H_2S and CO2 Concentration for Anti-Corrosion Measures in Gas Wells," SPE 81495 presented at the SPE 13th Middle East Oil Show & Conference, Bahrain, June 9-12, 2003

The author describes Saudi Aramco's study of H_2S and CO_2 measurement technologies to develop guidelines for on-site testing in gas wells. The purpose of the study was to develop dependable H_2S and CO_2 measurement to aid in proper and cost-effective selection of corrosion-resistant tubular goods. The author notes "In recent years, there has been a move away from chemical inhibition, due both to environmental or engineering limitations." He describes the use of various measurement techniques, such as: 1) using non-reactive downhole samplers with titration at the surface, 2) multi-gas monitor (electrochemical sensors); 3) Tutwiler titration; and 4) Drager tubes. The author describes comparison the various measurement techniques in tests on various wells. The results of the study and tests was the development of the guidelines, which are included as appendices to the paper.

Garber, J.D., et al, "A Model for Predicting Corrosion Rates in Oil Wells Containing Carbon Dioxide," SPE 66651 presented at the SPE/EPA Exploration and Production Environmental Conference, San Antonio, TX, February 26-28, 2003

This paper describes a consortium study, which successfully developed a corrosion prediction model specific to wells producing associated carbon dioxide. The authors describe in detail the elements of the model which include: temperature/pressure profile; phase behavior profile; flow dynamics profile; corrosion rate profile; and corrosion rate expert system. In tests on two wells in the field the model was shown to calculate corrosion rates close to actual measured rates. The model may be a good tool for predicting and preventing corrosion, which in turn would

reduce casing leaks and the need for well workovers. It follows that waste generation would be reduced.

Cassinis, R.B., et al, "Microbial Water Treatment: An Alternative Treatment to Manage Sulfate Reducing Bacteria (SRB) Activity, Corrosion, Scale, Oxygen, and Oil Carry-Over at Wilmington Oil Field – Wilmington, CA," SPE 49152 presented at the 1998 SPE Annual Technical Conference and Exhibition, New Orleans, LA, September 27-30, 1998

The authors describe the implementation of Microbial Water Treatment (MWT) in injection well fields for enhanced recovery. Previously, the operator had been treating injection wells with biocides, corrosion and scale inhibitors, and oxygen scavengers to control problems arising from the activity of sulfate-reducing bacteria. The injected water had a high sulfate concentration as a result of using sea water. The authors provide a thorough discussion of the MWT process (similar to "biocompetitive exclusion discussed in SPE 37438 below) and field observation methodology for assessment of MWT performance. The authors conclude that MWT was successful in controlling SRB and the associated problems. The use of MWT allowed the operator to discontinue the use of toxic biocides and inhibitors. The project also resulted in a 50% decrease in water treatment costs. As a bonus, oil production appeared to be enhanced.

Wright, M., et al, "Effect of Nitrate on Sulfide-Bioscavenging by Indigenous Bacteria in Produced Brines from West Texas Oil Fields," Proceedings of the 4th International Petroleum Environmental Conference, San Antonio, TX, September 9-12, 1997

The authors discuss the addition of nutrients to encourage indigenous bacteria to compete with sulfate-reducing bacteria (SRB). They present the results of testing various produced waters to determine the appropriate nutrient mix for effective SRB control. The primary nutrient is nitrate, but as the authors explain additional nutrients, such as yeast extract, may be necessary in certain formations. While nitrate alone may be effective for some applications, it also may actually cause an increase in sulfide generation in other circumstances. The authors explain these pitfalls and factors that should be considered in designing the correct treatment. Successful control of SRB reduces corrosion and, possibly surface treatment, which may generate waste.

This paper is available at http://ipec.utulsa.edu/.

Hitzman, D.O., and Dennis, D.M., "Sulfide Removal and Prevention in Gas Wells," SPE 37438 presented at the 1997 SPE Production Operations Symposium, Oklahoma City, OK, March 9-11, 1997

Hydrogen sulfide (H_2S) produced with fluids and gas usually results in increased corrosion. Typically, H_2S is generated in the formation by sulfate reducing bacteria. Typical treatments to control SRB include biocides. Also, regular treatments with corrosion inhibitors are required. The authors describe a well treatment that reduces the activity of SRB without the need for toxic biocides and that reduces the need for treatment with corrosion inhibitors. The treatment, called

"Biocompetitive Exclusion" uses nutrients (e.g., nitrates and nitrites) to enable competing microbes to consume available nutrients in the formation, thus reducing the SRB activity. The authors describe the treatment and offer three case histories of its successful use in the field. Waste minimization benefits obtained by using this treatment include elimination of the handling of toxic biocides, reduced need for corrosion inhibitor treatments, and reduced need for H_2S scavenging systems. The use of relatively non-toxic nutrients greatly reduces the potential for toxic waste generation.

Note: This paper was also presented as SPE 37908 at the 1997 SPE/EPA Exploration and Production Environmental Conference in Dallas, TX, March 3-5, 1997. SPE 37908 adds an additional case history of the field application of biocompetitive exclusion.

3.6 EROSION CONTROL FOR FLOWLINES

Serrano, J., and Peñalver, J., "Control of Erosion-Corrosion in Flowlines on Wells in Northern Monagas," SPE 23651 presented at the Second Latin American Petroleum Engineering Conference of the Society of Petroleum Engineers, Caracas, Venezuela, March 8-11, 1992

The authors present the results of erosion-corrosion studies on 31 flowlines from wells. Ultrasonic measurements were made on flowline sections extending from the wellhead standpipe to the anchor pile. The sections showed a wear range with respect to nominal thickness, and an estimated useful life of the lines was determined. These results matched erosion caused by aqueous slurries in lab studies. It showed that by increasing the pipe diameters and increasing the radius of 45 degree elbows there was a marked increase in the useful life of most critical lines. The effect of CO_2 and H_2S were of minimal concern in these cases. The extended useful life of flowlines and other tubulars reduces the waste generation associated with replacement.

3.7 CRUDE OIL RECLAMATION AND IMPROVED OIL/WATER SEPARATION

Parkinson, J.W., "Three Phase Centrifuge Technology for Minimizing Petroleum Waste," *Eye On Environment*, Vol. 2 No. 2, U.S. Department of Energy National Petroleum Technology Office (June 1997) 4-5

This article discusses the use of three phase centrifugation to recover salable oil from BS&W. The three phase centrifuge is capable of three distinct phase separations in a single pass. Three phase centrifuges are uncommon in the oilfield, but have been used in other industries. Oilfield separation is a much harder problem than most other industrial applications as the oilfield mixture is a solids-stabilized emulsion produced from a liquid-solid mixture that often contains small particles with relatively large surface areas. It is indicated that the centrifuge can recover "dead oil" that is unrecoverable using thermal and/or chemical techniques. The article has several flow and equipment set-up diagrams and a table giving three phase centrifuge separation data. This article gives one answer to recovering "dead oil" and reducing disposal of

BS&W. (Note: The three phase centrifuge requires a skilled operator to be effective. As of late 2002, an automatic control system had not been fully developed and proven.)

Polston, C.E., et al, "A Three-Phase Centrifuge to Minimize Waste from Production Tank Bottoms and Sludges: An Economic Analysis," SPE 29717 presented at the SPE/EPA Exploration and Production Environmental Conference, Houston, Texas, March 27-29, 1995

The authors discuss the operation and economics of the three phase centrifuge presented in the article referenced above ("Three Phase Centrifuge Technology for Minimizing Petroleum Waste," *Eye On Environment*, June 1997). The authors conclude that the use of a three-phase centrifuge system may be economically feasible, even for an operator. However, a mobile system operated by a service company should offer improved economics. In any case, the price of crude oil is a primary factor in determining economic feasibility. The authors use set criteria to show satisfactory internal rates of return for investments in various systems.

Hahn, W.J., "High-Temperature Reprocessing of Petroleum Oily Sludges," SPE 25931 presented at the 1993 SPE/EPA Exploration & Production Environmental Conference, San Antonio, Texas, March 7-10, 1993

The author describes a field test using high-temperature reprocessing (HTR) to recover crude oil from tank bottoms and skim oil. The field test was conducted at a steam-flood field in California and used surplus injection steam as the heat source. However, the process may prove useful in production operations where another source of heat would be required. The author provides a fairly thorough discussion of thermal treatment principals. The HTR process (which uses steam from the fields steam-flood boilers) is described and treatment parameters are discussed. The author does not address a HTR system that uses a different source of heat. In the described field test, a profit of $2 per barrel of processed hydrocarbon sludge was realized (note that recovered oil was sold at about $14/bbl). Once again, the need to acquire a source of heat, other than pre-existing steam generation, would have to be considered in other areas. The author concludes that a properly designed and operated HTR facility can be used to achieve volume reductions, to recover residual oil, to increase flash point, and to reduce the concentration of volatile organic compounds. HTR should be evaluated for cost-effective crude oil reclamation in other areas. (Note: This paper is reprinted in *SPE Production & Facilities* (August 1994) 179-182.)

Duke, R.B., "Demulsifying the Produced Fluids from Marathon's M-1 Project," SPE 24539, Unsolicited Paper, Society of Petroleum Engineers (1992)

This paper describes Marathon Oil Company's efforts to improve crude oil demulsification at a field producing crude oil with micellar/polymer flood enhanced recovery. Marathon Oil was producing fluid consisting of emulsions which could not be efficiently broken using commercially available demulsifiers (circa early 1980's). Two polyoxypropylene amines

(POPAs) that had been found to be effective demulsifiers in laboratory studies were chosen to be field tested for the project. Neither one of these chemicals was originally manufactured as a demulsifier. (Note that since publication of this paper, POPAs likely have become available as demulsifiers). This paper describes the project and the results of switching to POPAs. This project's intent was to more efficiently separate produced fluid into hydrocarbon gas, a liquid hydrocarbon phase and a water phase. However, the project also resulted in significant waste minimization. The project demonstrated that the use of POPAs increased operational efficiency, reduced the amount of chemical used by 50%, reduced the amount of required equipment (e.g., eliminated need for three out of four heater treaters), and reduced manpower requirements. This paper provides an excellent example of how product substitution and efficiency improvements can result in waste minimization.

Murti, D.G.K. and Al-Nuaimi, H.R., "Renovate Produced Water-Treating Facilities to Handle Increased Water Cuts," paper SPE 22831 presented at the 66th Annual Technical Conference and Exhibition, Dallas, Texas, October 6-9, 1991.

This paper describes modifications that can be made to surface separation equipment to improve crude oil removal from produced water. The authors provide a detailed description of enhanced skimming and recovery after retrofitting a skimming tank with improved oil and water weirs and baffles. The authors claim increased oil recovery at one tank battery from 6 barrels per day to over 55 barrels per day. Illustrations are given for baffle modifications and the process flow.

Andrist, C.R., "Gas Turbine Exhaust Heat Recovery Applied to Emulsion Treating System," SPE 7406 presented at the 53rd Annual Fall Technical Conference and Exhibition of the Society of Petroleum Engineers of AIME, Houston, TX, October 1-3, 1978

Although this paper is a bit dated, it provides an excellent example of improved operating efficiency to reduce the demand for fuel. The author describes the design and operation of a system to recover heat for treating emulsified crude oil. The water injection system for enhanced recovery (i.e., pressure maintenance) at the producing field in West Texas used several large gas turbine engines to drive injection pumps. The system used the waste heat from the turbine exhaust, through a heat medium oil, to aid in breaking the emulsions, which was necessary to produce pipeline quality crude oil. The author states that the economics were "very attractive," despite less quantity of saved fuel than expected.

3.8 ELECTRIC POWER EFFICIENCY AT PRODUCTION SITES

General

Torr, D., "Web-Based Pump-Off Controller Reduces Electricity Costs," Petroleum Technology Transfer Council/*World Oil*, Case Studies - Petroleum Technology Digest (September 2001) This article is available on the PTTC web site at http://www.pttc.org/case_studies/case_studies.htm

This article describes how an independent based in Denver, Colorado, and McKinney, Texas, implemented a web-based system to improve operating efficiency. The independent operates more than 120 oil wells in Lander, Wyoming. These wells are located in a remote region that is difficult to reach due to the rough terrain and harsh winter climate. To better manage its waterflood and oil production activities, the operator installed web-based pump-off controllers. Electricity costs were reduced by about 15%, and the operator fully expects to realize additional value from production optimization, reduced well servicing costs and quicker response times.

Hall, C.H., "How To Cut Electrical Power Costs by 30% With Little or No Investment," Petroleum Technology Transfer Council/*World Oil*, Case Studies - Petroleum Technology Digest (May 2000) This article is available on the PTTC web site at http://www.pttc.org/case_studies/case_studies.htm

The author provides a step-by-step methodology for assessing operations to identify electrical power cost savings opportunities. The article also includes a few brief case histories of oil producers who successfully reduced costs.

Coston, D., and Dicus, B.J., "How to Reduce Electrical Power Costs Without Sacrificing Production Rate," Petroleum Technology Transfer Council/*World Oil*, Case Studies - Petroleum Technology Digest (September 1999) This article is available on the PTTC web site at http://www.pttc.org/case_studies/case_studies.htm

This case history describes how an oil producer reduced electrical costs by using timers to pump during off-peak (electrical demand) hours. The article describes how the operator maintained production levels while reducing power costs.

PTTC, "Electrical Power Cost Reduction Methods in Oil and Gas Fields," Workshop Summaries, Solutions From the Field, http://www.pttc.org/solutions/oper.htm (October 13, 1998, and March 24, 1999)

This PTTC summary is based on presentations at the Central Gulf Region Workshop held in Shreveport, Louisiana, in October 1998 and in Lafayette, Louisiana, in March 1999. The workshop addressed electric power use in producing oil and gas. Electric power can account for 10% to 40% of the total lifting costs of producing oil and gas. At lower oil prices, the impact

of lifting cost reduction on revenue economic is amplified. To reduce power and lifting costs, operators must employ a systems approach, understand the well and lease equipment, and evaluate a variety of options. Operators can reduce electrical power costs by improving artificial lift efficiencies, using total well management, generating their own electricity, and seizing opportunities created by electric restructuring. Reducing energy consumption in turn reduces emissions associated with electric power generation. Also, more efficient equipment operation reduces wear and the need for maintenance and repair, therefore reducing waste generation. The workshop summary discusses techniques such as the use of timers and pump-off controllers to pump during off-peak hours; *c*ounterweight balancing; power shaft systems; and self-generation of electricity. Examples of the successful implementation of these techniques by independent producers are provided. Also, the summary lists operating and service company contacts for obtaining additional information on energy efficiency technologies. The total well management process can take less than three hours per well and can lead to significant savings.

Paik, M.E., "Reducing Electric Power Cost in Old Oil Fields," SPE/DOE 35408 presented at the 1996 SPE/DOE Tenth Symposium on Improved Oil Recovery, Tulsa, Oklahoma, April 21-24, 1996

The author discusses methods of controlling the cost of electricity in producing oil from older fields. In older fields, the cost of electric power is one of the larger, if not the largest, operating cost. The author suggests different paradigms for managing electricity and different paradigms for field operating practices. This change in focus is essentially procedural, generating significant increases of economically recoverable reserves at minimum incremental investment. In the author's hierarchy of power cost reduction projects, the primary focus is developing a relationship with electric power providers (e.g., meeting with power company managers), just as you would with a well servicing or pipe company. In other words, develop an understanding of power rates, types of power costs, and the power company's methods of business. The discussion includes a fairly detailed description of the types of electric power charges and rates. The author offers suggestions for procedural and equipment changes to reduce power consumption; but, such changes are suggested as a secondary efforts to reduce electric power costs. The author's basic premise is that electric power costs should be carefully and thoroughly managed by employees who are held accountable for performance.

Bullock, J.E., "Electrical Savings in Oil Production," SPE 16363 presented at the SPE California Regional Meeting, Ventura, California, April 8-10, 1987

The author describes procedures that can be taken to reduce electricity consumption in the oilfield. The discussion includes a description of various motors and equipment that impact power consumption. Pacific Gas and Electric field tested over 300 sucker rod pumping unit motors and 200 production facility motors, and identified methods that an operator can implement with minimal expense to reduce his electric bill. The author describes methods of improving electrical, efficiency, including: installing pump-off controllers and timers; modifying pumping unit stroke length and speed; using multi-mode motors in low mode; and improving

power factor with capacitors Application of these methods can result in less wasted energy and lower electric bills

Rod Pump Efficiency

OGJ Technology Report, "Modifications Improve Beam-Pump Performance," *Oil and Gas Journal* (April 6, 1998) 60-61

This article briefly summarizes a project to improve rod-pump performance, mainly by reducing electricity consumption and costs. The project was sponsored by the Kansas Corporation Commission and supported by U.S. DOE funding. OXY USA, DynCorp and Midwest Energy assisted in the project. The results of the project demonstrated that electrical and mechanical modifications to the pumping unit can reduce electrical demand and energy consumption, as well as help reduce air emissions from power generation sources. Modifications include using smaller electric motors, minimizing power losses in service conductor, adding capacitors to improve power factor, pump unit maintenance and optimization (e.g., dynamic balancing, replacing worn parts and belts). (Note: The article cites a project report titled "An Investigation of Methods for Reducing the Cost of Pumping Oil in Kansas; co-authored by DynCorp and Center for Energy Studies at Wichita State University. The report is available at http://www.oit.doe.gov/bestpractices/motors/mc-cs09.shtml.)

PTTC, "Tips for Reducing Beam-Pumped Lifting Costs" New Technology Summary reprinted from the "PTTC Network News" (2nd Quarter 1998)

This article offers experience-based tips for improving pump efficiency and reducing costs. The tips were offered by Cecil Hunt, chief engineer for Lufkin Industries, Inc., during a half-day workshop for the Society of Petroleum Engineers' Mid-continent Section. This article is available on the PTTC web site at http://www.pttc.org/tech_sum/ts_071.htm. Tips discussed include:

- Maintain low flowline pressures.
- Properly size the electric motor.
- Produce with a full pump barrel.
- Properly tighten sheave belts.
- Use as long a stroke and as large a pump as practical.
- Select the optimum pumping unit geometry.
- Optimize the direction of rotation.
- Maintain proper balance.

Kilgore, J.J., et al, "Walking Beam Pumping Unit System Efficiency Measurements," SPE 22788 presented at the 66th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Dallas, Texas, October 6-9, 1991

The authors present and discuss measurements that have been made on wells at several Shell Development Co. locations and on a specially designed walking beam pump test stand at Lufkin Industries. These measurements were made in order to determine the overall system efficiency of individual components. The results of this work show that the overall beam pumping system efficiency is normally between 48% and 58%. Efficiency is primarily dependent on pump size, tubing size, and rod sizes. Typically, the surface unit efficiency (including the motor) is between 60% and 75%, and the subsurface equipment efficiency is between 70% and 85% for well designed systems. The authors suggest that for improving system efficiencies: 1) the pumping unit should be sized so the peak gearbox torque is near the gearbox rating; 2) the motor should be sized to operate at 50% to 70% of its nameplate rating when possible (however, the motor must have sufficient starting torque); and 3) subsurface losses as a function of well depth can be minimized by selecting the largest tubing and pump size possible and operating the unit at the lowest speed that will achieve the desired production. Improving pump efficiency would reduce the consumption and cost of electrical power and concurrently reduce the quantity of waste generated at the power generation source.

Neely, A.B., et al, "Power Savings and Load Reductions on Sucker Rod Pumping Wells," SPE 19715 presented at the 64th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, San Antonio, TX, October 8-11, 1989

Shell Development Co. and MagneTek Inc. conducted a joint test program to investigate the potential for power savings and load reduction on sucker rod pumped wells. This paper describes the results of the tests. The tests were conducted on conventional and Mark II units and on NEMA ""D"" and ultra-high slip motors. Silicon-controlled rectifiers (SCRs) were used to turn electrical motors off for one or two intervals during each power stroke. Using the SCR device reduced rod loads and peak gearbox torque, or power consumption by 5% to 15% on most of the wells tested. At the time of this paper's publication, 1989, a microprocessor-controlled prototype unit was being designed and tested. This SCR controller was to have four operating modes: 1) minimize energy consumption, 2) minimize rod/gear box loading, 3) maximize pumping efficiency, or 4) improve overall performance by optimizing the above modes. The use of SCR controllers would result in waste minimization in several ways. For example: reduced energy consumption would, in turn, reduce waste generation associated with power generation; and reduced rod/gear box loading would reduce the wear on pumping equipment and the waste generation associated with the resulting well workovers. The operator would also benefit from reduced costs for the pumping operation.

3.9 PRODUCED WATER

General

Reynolds, R.R., and Kiker R.D., "Produced Water and Associated Issues," Petroleum Technology Transfer Council (2003)

This manual provides useful guidance for managing and reducing produced water, reducing lifting costs, and controlling corrosion and mechanical wear. The PTTC developed this manual, with U.S. DOE support, as a reference source to assist independent operators in dealing with produced water. Much of the information in this manual was compiled from workshops conducted by the PTTC. The manual is divided into eight sections to better address the different technologies used for different water production issues operators face throughout the life of a well. Not all technologies discussed are applicable to all situations, but they have led in certain situations to improved return on investment and increased economically recoverable reserves. The manual, which is user-friendly, may be downloaded from their website at http://www.pttc.org/pwm/produced_water.htm

R. S. Seright, et al, "A Strategy For Attacking Excess Water Production," New Mexico Petroleum Recovery Research Center, New Mexico Tech, Socorro, NM (2003)

This report describes a straightforward strategy for diagnosing and solving excess water production problems. The strategy advocates that the easiest problems should be attacked first and diagnosis of water production problems should begin with information already at hand. A listing of water production problems is provided, along with a ranking of their relative ease of solution. Although a broad range of water-shutoff technologies is considered, the major focus of the report is when and where gels can be effectively applied for water shutoff. This PRRC report, which also was published in *SPE Production & Facilities* (August 2003), is available on the PRRC web site at http://baervan.nmt.edu/randy/.

PTTC, "Advanced Technologies for Managing Produced Water," Workshop Summaries, Solutions From the Field, http://www.pttc.org/solutions/oper.htm (March 10, 1998)

This PTTC summary is based on presentations at the Appalachian Region Workshop held in Columbus, Ohio, in March 1998. The workshop presenters discussed various techniques for controlling water production. Produced water must be treated, removed, and disposed of at a re-injection disposal cost of $ 0.25 to $ 0.50 per barrel (if it must be trucked, costs can raise to $1.50 per barrel). The technologies presented in the workshop can reduce the quantity of produced water that must be managed at the surface, therefore reducing disposal costs. The summary provides a general discussion of polymer gel treatments, dual-completion water sinks, and dual-action pumping systems for downhole oil/water separation. The operational and economic results of successful field application of these technologies is provided. Also, the summary lists operating and service company contacts for obtaining additional information on the technologies.

Formation Treatment to Reduce Water Production

Numerous techniques have been developed to reduce water production through formation treatment. Many involve the use of gels or precipitates which are intended to selectively reduce the permeability of the formation to water (referred to as "conformance technology"). Such treatment has limitations and pitfalls, but can be successful when properly designed. These technologies have been intensively researched as demonstrated by many of the following technical papers. Because research is ongoing, the most recent papers and articles will be most useful. However, previous papers may also provide useful information. Note that the New Mexico Petroleum Recovery Research Center (PRRC) at New Mexico Tech in Socorro, NM, is conducting conformance technology research and is an excellent source of information on the subject (http://baervan.nmt.edu/randy/). Several of the following references are authored by researchers at the PRRC.

Di Lullo, G., et al, "New Insights into Water Control – A Review of the State of the Art – Part II," SPE/Petroleum Society of CIM/CHOA 79012 presented at the 2002 SPE/PS-CIM/CHOA International Thermal Operations and Heavy Oil Symposium and International Horizontal Well Technology Conference, Calgary, Alberta, Canada, November 4-7, 2002

The authors provide a very good discussion of water control technologies. They describe the critical parameters related to conformance treatment and the types of treatment systems, such as permeability blockers, disproportionate permeability reducers (DPR), selective permeability blockers (SPB), and relative permeability modifiers (RPM). Of particular interest, the authors provide a very good discussion of the "conformance-fracture concept" and relevant case histories. Conformance-fracture is a technique that combines a hydraulic fracturing stimulation with a water control mechanism. The case histories demonstrate that conformance-fracturing can be very effective in reducing produced water cut.

Seright, R., and Liang, J.T., "Sizing Gelant Treatments in Fractured Production Wells," Proceedings of the 1999 Oil and Gas Conference, U.S. Department of Energy National Energy Technology Laboratory, Dallas, TX, June 28-30, 1999 (Note: This paper is available on the U.S. DOE web site at www.netl.doe.gov/publications/proceedings/99/99oil&gas/99o&g.html.)

This presentation by the New Mexico Petroleum Recovery Research Center (PRRC) provides an engineering basis for designing and sizing gelant treatments in hydraulically fractured production wells. The treatment is intended to stop the increased production of water from fractures which break into water zones. The presentation presents a simple 11-step procedure using a user-friendly graphical-user-interface software called "Gel Design." The software is available on the PRRC web site at http://baervan.nmt.edu/randy/.

Creel, P., and Crook, R., "Foamed Cement Solves Producing, Injection Problems," *Oil and Gas Journal* (January 12, 1998) 4145

The authors' describe how a foamed cement squeeze was used to block injection water channeling to offset producing wells. The authors discuss the advantages of foamed cement and indicate that in the described application foamed cement was placed at a lower cost than for polymers or gels. Also, the article addresses the techniques used to identify the channeling problem and design the formation treatment. The result of the foamed cement squeeze was elimination of the production of excess channeled water and improved oil recovery.

Seright, R.S., A Review of Gel Placement Concepts," PRRC 96-21, New Mexico Petroleum Recovery Research Center, New Mexico Tech, Socorro, NM (July 1996)

This report presents a summary of PRRC's work (as of 1996) on the topic, including permeability modification to reduce water production and improve reservoir sweep. The objective of gel treatments and similar blocking-agent treatments is to reduce channeling through fractures or high-permeability zones without significantly damaging hydrocarbon productivity. PRRC's work focuses on maximizing gel penetration and permeability reduction in high-permeability, watered-out zones, while minimizing gel penetration and permeability reduction in less-permeable, hydrocarbon-productive zones. Detailed documentation of each concept can be found in provided references. This paper is available on the PRRC web site at http://baervan.nmt.edu/randy/.

The author and others have published numerous technical papers on water shutoff using gels, foams, particulates, precipitates, microorganisms, and emulsions. Many of the papers describe laboratory tests, though some offer practical information regarding the technology. The following list includes some papers authored or coauthored by researchers at the PRRC:

> Nimir, H.B., and Seright, R.S., "Placement Properties of Foams Versus Gelants When Used as Blocking Agents," SPE 35172 presented at the Permian Basin Oil & Gas Recovery Conference, Midland, TX, March 27-29, 1996
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> Seright, R.S., and Liang, J., "A comparison of Different Types of Blocking Agents," SPE 30120 presented at the European Formation Damage Conference, The Hague, The Netherlands, May 15-16, 1995
>
> Liang, J., et al, "Why Do Gels Reduce Water Permeability More Than Oil Permeability," SPE 27829 presented at the SPE/DOE Ninth Symposium on Improved Oil Recovery, Tulsa, OK, April 17-20, 1994
>
> Liang, J., et al, "Reduction of Oil and Water Permeabilities Using Gels," SPE 24195 presented at the SPE/DOE Eight Symposium on Enhanced Oil Recovery, Tulsa, OK, April 22-24, 1992

Sorbie, K.S., et al, Gel Placement in Heterogeneous Systems With Crossflow," SPE 24192 presented at the SPE/DOE Eight Symposium on Enhanced Oil Recovery, Tulsa, OK, April 22-24, 1992

Seright, R.S., "Impact of Permeability and Lithology on Gel Performance, " SPE 24190 presented at the SPE/DOE Eight Symposium on Enhanced Oil Recovery, Tulsa, OK, April 22-24, 1992

Evans, R.C., "Developments in Environmental Protection Related to Produced Water Treatments and Disposal (Produced Water Reinjection)," SPE 27179 presented at the Second International Conference on Health, Safety & Environment in Oil & Gas Exploration & Production, Jakarta, Indonesia, January 25-27, 1994

In spite of the paper's title, the author discusses the reservoir engineering and produced water treatment requirements for successful water-flooding for enhanced oil recovery. More specific to waste minimization, the author provides a brief discussion of methods to reduce produced water quantities. The methods include the use of chemical and cement formation squeezes and well completion design.

Thompson, K.E., and Fogler, H.S., "A Study of Diversion Mechanisms by Reactive Water-Diverting Agents," SPE 25222 presented at the SPE International Symposium on Oilfield Chemistry, New Orleans, LA, March 2-5, 1993

The authors describe a study performed in order to gain a mechanistic understanding of the pore level interactions between oil, water and organic diverting agents (that gel or precipitate), the porous media, and the generated precipitate. The paper includes limitations of diverting agents, e.g., circumstances where permeability to oil may be damaged. The authors note that injection of diverting agent followed by flowback of produced fluids during precipitation may overcome these limitations.

Dahl, J.A., et al, "Current Water-Control Treatment Designs," SPE 25029 presented at the European Petroleum Conference, Cannes, France, November 16-18, 1992

In this paper, different types of water-producing wells are classified corresponding to their onset mechanisms. Various applications of polymers and cements in minimizing the water-oil ratio are evaluated. A general procedure for designing water-control treatments is presented. This paper also addresses difficulties existing in design and performance of water-control treatments. These include (1) lack of an extensive production history and knowledge of prior stimulation of wells requiring treatment, (2) lack of a systematic approach in treatment design, and (3) improper recovery techniques when returning the well to production. Results of wells treated in various fields are evaluated with respect to methods and chemicals used. Information presented in this paper will provide the completion engineer a broad knowledge of available (at the time of publication) water-control treatment design parameters and chemical applications. Ideally, the

engineer may then determine an effective technique for reducing water production for the specific circumstances.

Gunningham, M.C. et al, "Through-Tubing Remedial Treatments Using a Novel Epoxy Resin System," SPE 24986 presented at the European Petroleum Conference, Cannes, France, November 16-18, 1992

An epoxy resin has been developed, with a solvent system that is compatible with high-expansion elastomers. The versatile epoxy resin system can thus be used with through tubing straddle packers to treat intervals selectively. The system can be used for sand consolidation, water shut-off and cement repairs. This paper describes the laboratory testing of the new system, various applications of the novel epoxy resin and a case history of the first field trial. Laboratory testing of the system has shown that for sand consolidation the system gives 80-90% return permeability while resulting in increases in unconfined compressive strength of typically 50-70 bar. The system can also be used for shut-off purposes, reducing permeability to water by 99%. Gas shut-off may be less effective. The new resin system produces consolidated sand packs with low moduli of elasticity, which may allow them to survive pressure fluctuations better than more rigid formations. The compatibility of the system with high-expansion straddle packers has been field proven.

Littlefield, B.A., et al, "Case Histories of New Low-Cost Fluid Isolation Technology," SPE 24802 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum engineers, Washington, DC, October 4-7, 1992

The authors describe in good detail a treatment process developed by Texaco to shut off steam and water encroachment in producing wells. The process consists of placing a stable Furan-resin system across the zone to form an impenetrable plug which shuts off encroaching water. The plug is stable at 700°F and inert to usual oilfield chemicals. A technological advantage of this system over cement is the penetration of the formation through liquid migration and ease of placement by using a dump bailer. This paper gives the results of treatment tests in 1990 and 1991 on 33 wells that had water encroachment, steam cutting, casing holes or injection well leaks. In the tested wells (in Texaco's Kern River Field and San Ardo Field) about seventy percent wells showed a significant reduction in water production after treatment. A summary of the data and results for the treated wells is provided.

This technique is also discussed by the authors in the following paper, which also describes the use of the furan resin for sand control.

> Fader, P.D., et al, "New Low-Cost Resin System for Sand and Water Control," SPE 24051 presented at the Western Regional Meeting, Bakersfield, California, March 30 –April 1, 1992

Dalrymple, E.D., et al, "A Selective Water Control Process," SPE 24330 presented at the SPE Rocky Mountain Regional Meeting, Casper, Wyoming, May 18-21, 1992

The authors describe the development of a selective water control process. This process incorporates small particle size cement (SPSC) in an oil based slurry that also contains a surfactant. The system allows high concentrations of SPSC in the oil and retards the SPSC reaction with water to allow deep penetration into high permeability microchannels and fractures to shut off water. The slurry will set only if it contacts mobile water and therefore provides an excellent water control treatment. The selective water control process has been used in conjunction with polymers crosslinked by metal crosslinkers to obtain reduction of water without the problems associated with crosslinked polymer, i.e., polymer production with accompanying corrosion and bacteria problems. This paper demonstrates the application of selective water control process in various types of formations, ranging from sandstone to fractured limestone, dolomite, and chert. Field case histories of the process are presented for perforated and openhole completions.

Ventresca, M.L., and Torres, G., "Control of Water Production in Reservoirs with High Temperature Produced by Water Drive," SPE 23672 presented at the Second Latin American Petroleum Engineering Conference, II LAPEC, of the Society of Petroleum Engineers, Caracas, Venezuela, March 8-11, 1992.

The authors evaluated three commercial gelifying systems (proprietary, and apparently polyacrylamides) for selectively reducing permeability to water in high temperature sandstone reservoirs. The paper primarily describes laboratory tests using Berea cores intended to determine the best system for use in water-drive reservoirs in Venezuela. The test results are interesting; however, the authors cite actual field results provided by the suppliers, which are more telling. In an application of a non-sealing* system in Mississippi, a sandstone reservoir experienced an 80% reduction in water production (initially 2,100 bpd) accompanied by a 50% increase in crude oil production (eventually the crude oil production rate returned to pre-treatment levels). Also, a treatment using a sealing* system (location not given) squeezed into the water zone resulted in an 88% reduction in produced water and a significant crude oil production increase. The sealing system also was effective in plugging fissured "thief zones" in a water injection well. (*Non-sealing system means permeability to water is reduced and permeability to crude oil is less affected. Sealing system means permeabilities to both crude oil and water are reduced.)

Zaitoun, A., et al, "Thin Polyacrylamide Gels for Water Control in High-Permeability Production Wells," SPE 22785 presented at the 66th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Dallas, TX, October 6-9, 1991

This paper describes the laboratory evaluation of a new system for water control applications in high permeability wells. The system tested and proposed is a thin completely non-ionic gel produced by the reaction of polyacrylamide homopolymer (PAM) with a non-ionic organic cross-linker (OC). PAM and OC are cited as common commercial products without any major

environmental restrictions on their use. The paper provides a detailed description of the laboratory evaluation of the PAM/OC system and compares the system to the effectiveness of polymer without a cross-linker. Conclusions of the evaluation included: 1) the PAM/OC reaction depended little on salinity and temperature (gel stable up to 70 degrees C). Optimum pH was between 6 and 8.5, which corresponds to usual reservoir conditions, 3) the thin gels induced a considerable drop in the relative permeability to water (>100) with respect to the drop in relative permeability to oil (<3.5), showing the systems great selectivity, and 4) the efficiency of a thin gel, in selectively reducing water mobility with respect to oil was an order of magnitude greater than for the single polymer. (In 1991, the authors predicted that the PAM/OC water control treatment would have a wide field of application.)

Peavy, M.A., "Successful Water Control in Openhole Gravel-Packed Completions Within a TEOR Environment," SPE 22778 presented at the 66th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Dallas, TX, October 6-9, 1991

The successful application of a phenolic resin plugback technique for reduction of produced volume water is presented in this paper. The project involved thirty-two wells in a field with thermally enhanced oil recovery (TEOR) in use. The productive interval (9 to 12 degree API oil) ranged from a depth of just below ground surface to below 2,000 feet. The paper addresses the development, implementation, and results of this water control technique. In general, the plugback technique was to shut off the water-producing zone by sealing it with phenolic resin plug using a catalyst designed to cause the resin to set at the expected temperature. The program resulted in a decrease in produced water volume of 5,850 BWPD (approximately 183 BWPD per well) and an increase in oil production of 256 BOPD (approximately 8 BOPD per well). The author calculated that the project payout was 120 days. The benefits from the phenolic resin plugback program were a sum of oil production revenues, water disposal cost reductions and oil treating dehydration heat savings. This water control technique case history is for a shallow, low temperature reservoir undergoing TEOR. However, the procedure may be applicable to perforated casing completions in more conventional reservoirs.

Completion Techniques to Reduce Water Production

Braas, J.C.M., et al, "Water Production Management – PDO's Successful Application of Expandable technology," SPE 81489 presented at the SPE 13th Middle East Oil Show & Conference, Bahrain, April 5-8, 2003

The authors describe the use of Solid Expandable Technology (SET) to shut off water production in open-hole, horizontal well completions in a fractured carbonate (reef) reservoir. The paper briefly describes the types of SET systems and the basis for their choice of the Expandable Open Hole Clad. The paper also addresses the formation evaluation and well logs necessary to accurately identify the location of fractures producing water. A case history is presented, which demonstrated the effectiveness of the technique in a producing well. Water cut was decreased and oil production increased over 100%, and improved production provided economic payback. The authors also include a case history for the use of the OHC system to

isolate a thief zone in an injection well, which had impacted oil production in a nearby well. In that instance, a swelling elastomer was used on the OHC to assure contact and seal with the borehole wall. The technique was also successful in this case, in that oil production was increased, while water injection decreased. IN each case history, the authors describe the steps taken to set the OHC. This paper discusses a produced water reduction technique specific to fractured carbonate reservoirs, which may be of interest to operators producing from similar reservoirs.

Swisher, M.D., and Wojtanowicz, A.K., "In Situ-Segregated Production of Oil and Water - A Production Method With Environmental Merit: Field Application," SPE 29693 presented at the SPE/EPA Exploration & Production Environmental Conference, Houston, TX, March 27-29, 1995

This paper describes field implementation of a completion method for water-driven, flowing wells which enhances the production rate of water-free oil while eliminating hydrocarbon contamination of produced water. The method involves a dual completion in the oil zone and the water zone. The water zone completion is separated by a packer and 3 1/2 inch tubing, and water production is assisted by a downhole progressing cavity pump. Concurrent production of oil and water controls the position of the oil-water contact. The paper presents detailed data for the project. The paper concludes that this completion technique is economically advantageous for three reasons: (1) oil production can be maintained at a higher level though payout, (2) produced water is basically oil-free, which eliminates the need for separation at the surface, and (3) payout of the test well was expected to occur in half the time of a conventional well.

Guo, B., and Lee, R.L., "Determination of the Maximum Water-Free Production Rate of a Horizontal Well With Water/Oil/Interface Cresting," SPE 24324 presented at the SPE Rocky Mountain Regional Meeting, Casper, Wyoming, May 18-21, 1992

The authors, of New Mexico Inst. Of Mining and Technology, discuss the theoretical and numerical analysis of water-oil-interface cresting behavior in horizontal wells. The purpose of this paper is to find a simple approach to determination of the maximum water free production rate of horizontal wells with water-oil-interface cresting and to determine the location of the water-oil-interface under critical conditions. The maximum water free oil production rate and lateral extension of the calculations are confirmed by numerically simulated reservoir which matches field data. This paper includes high level math ("conformal mapping theory") in the arriving at the solution. Using this type of analysis to control oil/water interface cresting may result in waste minimization, i.e., reducing the quantity of produced water.

Wojtanowicz, A.K., et al, "Oilwell Coning Control Using Dual Completion With Tailpipe," SPE 21654 presented at the Production Operations Symposium, Oklahoma City, OK, April 7-9, 1991.

The authors discuss the possibility of controlling water production by concurrently producing oil and water from separate completions. They present and discuss mathematical models (in detail) for predicting the behavior of an oil-water contact (OWC) in response to oil production rate and concurrent water production rate. Though the paper does not include an actual field test, the authors applied the model to an actual field well. The model fit very closely the actual performance of the well (i.e., the model prediction matched the timing of water cone breakthrough in the oil perforations). The authors believe this completion technique can increase oil recovery while decreasing total water production. Also, oil-free water brought to the surface requires less treatment prior to disposal or use in enhanced recovery, and oil requires less processing.

Downhole Oil, Gas, and Water Separation

Downhole oil (and gas) water separation DOWS and injection of produced water is an emerging technology. Various designs for DOWS have been installed in numerous wells with success, but there also have been shortcomings. DOWS designs use either gravity or mechanical separation (e.g., hydrocyclone) to separate the oil and water, which then is disposed of in the same well (or injected into a productive reservoir for enhanced recovery). The waste minimization benefit of the successful use of DOWS is the significant reduction of the produced water quantities managed at the surface, thus minimizing generation of wastes associated with water management and the potential for spills. The following technical papers and articles provide a good discussion of DOWS technology. (Note that more recent papers have not been annotated, but may have the paper's abstract. Annotations will be added for these papers as they become available to the Program.)

Bangash, Y.K., and Reyna, M., "Downhole Oil Water Separation (DOWS) Systems in High-Volume/ High HP Application," SPE 81123 presented at the SPE Latin American and Caribbean Petroleum Engineering Conference, Trinidad, West Indies, April 27-30, 2003

The authors describe the recognized benefits of DOWS technology and argue it is underutilized because of complicated system design and misapplication of the technology. Their discussion focuses on various factors which must be considered, such as individual downhole components and producing reservoir and injection formation characteristics. Of more interest, the authors describe the design and field test of a newly developed Encapsulated DOWS System. The system is claimed to minimize some of the factors responsible for premature failure, such as plugging of smaller tubes in integrated systems. The authors briefly describe the field test in a well in the La-Victoria Field. Unfortunately, the test was unsuccessful. However, this paper provides good information on the concept, design, and implementation of the Encapsulated DOWS System.

Jokhio, S.A., et al, "DOWS (Downhole Oil-Water Separation) Cross-Waterflood Economics," SPE 75273 presented at the SPE/DOE Thirteenth Improved Oil Recovery Symposium, Tulsa, OK, April 13-17, 2002

Abstract: Downhole oil-water separation (DOWS) provides the ability to conduct a cross-waterflood using a single wellbore that penetrates stacked waterflood zones. In this application of DOWS technology, production from one waterflooded zone is used as the inlet stream to the separation process. The oil-rich stream is produced to the surface while the water stream is injected into the second zone as shown in Fig.5.

Potential benefits include reduced well count, reduced lifting costs, reduced expenditures for surface water handling facilities, reduced treating costs, smaller surface footprint and reduced environmental risk. Potential disadvantages include DOWS installation costs, more expensive workovers, more difficult and costly monitoring and larger wellbore requirements.

DOWS technology is widely viewed as a potentially highly valuable technology with a high price tag and a high risk of failure. A major failure node for DOWS installation is the injection zone. Injection into a water flooded zone reduces the injectivity problems, and provides a benefit from the work required to inject the water stream. If a DOWS installation can economically be justified on its own merits anywhere, it will be in a cross-water flood application. The question remains; Can a DOWS cross-water flood be economically justified?

This paper is divided in four parts. First, DOWS technology in general and cross-waterflood application in particular are briefly described. Second, the operational advantages and disadvantages of this application of DOWS technology are briefly discussed. Thirdly the parameters of economic model are reviewed in some detail. Lastly, the characteristics of a waterflood operation that can benefit economically from this technology are summarized.

Scaramuzza, J.L., et al, "Downhole Oil/Water Separation System – Field Pilot – Secondary Recovery Application Project," SPE 69408 presented at the SPE Latin American and Caribbean Petroleum Engineering Conference, Buenos Aires, Argentina, March 25-28, 2001

Abstract: It is widely known the adverse impacts that the continuous increase in the volume of produced water has on oil production operation and reserves recovery. New technologies have been successfully developed and implemented to minimize de economic and environmental consequences of water production.

The Down hole oil/water separation system (DOWS), which was developed by the Centre for Engineering Research Inc. (CFER), allows to separate the produced water down hole and its later injection on the same well.

The system has proved to be technically and economically profitable in mature reservoirs reducing the lifting cost, production facilities cost and environmental risk associated with the handling of large volumes of produced water at surface.

Repsol-YPF produce, separate, treat and dispose of over half million barrels of water per day in La Ventana and Vizcacheras fields in the Cuyo basin in Mendoza province. They produce 29° and 30°API oil respectively with a high percentage of water.

A pilot field trail was carried out in these fields using DOWS technology. This equipment was installed on two wells producing with electrical-submersible pumps, one in VM-097 well (La Ventana) and the other in Vi-284 well (Vizcacheras).

This report describes the separation system implemented, the candidate wells selected, the results of the pilot field trails and the current flooded project based on Vizcacheras pilot result.

Blanco, A.E., and Davies, D.R., "Technical & Economic Application Guidelines for Downhole Oil-Water Separation Technology," SPE 67182 presented at the SPE Production and Operations Symposium, Oklahoma City, OK, March 24-27, 2001

Abstract: Downhole Oil-Water Separation (DOWS) is a water management technology consisting of a hydrocyclone to separate oil from water together with some form of artificial lift to produce an oil enriched stream to surface and to inject the bulk of the produced water into a disposal zone. Field trials have proven DOWS's operational success at reducing the well's water production, but economic success has been sparser. Increased confidence in DOWS technology depends on the development of improved models and methodologies which:

Realistically simulate the complete downhole separation process and

Evaluate the operational and economical aspects of DOWS

This paper summarises:

1. The development of a hydrocyclone performance model,

2. Its integration with a reservoir simulator and

3. The testing of this integrated model against a real field case leading to a reservoir development strategy for evaluating the optimum time for DOWS installation and DOWS economics.

Our single or dual stage, hydrocyclone performance model allows the oil / water separation efficiency to be calculated for a range of operational conditions. A decision tree identifies the optimum DOWS installation time based on both the economical and the operational aspects of the technology.

The impact of operational parameters on DOWS viability are assessed, ranked and compared. These include the importance of casing size, electrical power costs, properties of the water disposal zone, potential use of the reject water and the surface water treating costs. As expected, DOWS mechanical reliability is one of the key parameters controlling economic viability.

Use of our DOWS technical and economic models described here, together with the reported application strategy, will allow confident installation of DOWS technology in the field. DOWS may then be counted as a reliable option in the water management armoury and a tool for improved oil recovery.

Rudolph, J., and Rueter, C., "Technology Assessment and Economic Evaluation of Downhole Gas/Water Separation and Disposal Tools," Proceedings of the 6th International Petroleum Environmental Conference, Houston, TX, November 16-18, 1999

This paper summarizes the results of a study of down-hole gas-water separation (DGWS) and disposal performed by the Gas Research Institute (now Gas Technology Institute). The paper explains the type of DGWS that is appropriate for various producing circumstances (e.g., well depth, production rate, and disposal zone properties). Although the study addresses DGWS technology available in 1999, it may still be useful to operators interested in the subject. GRI and its contractor, Radian International, assessed the various types of DGWS systems and 53 field applications. The authors conclude that "Downhole gas/water separation is a promising, effective technology for increasing well profitability and minimizing environmental c9oncers by eliminating the generation and handling of produced water on the surface." The study resulted in an economic screening tool, which may be used to assess the feasibility of DGWS installation in a well. The study and the economic screening tool has been published by GRI (see the following note).

Note: "Technology Assessment and Economic Evaluation of Downhole Gas/Water Separation and Disposal Tools" (GRI-99/0218), October 1999, is available on the Gas Technology Institute web site at www.gri.org. The publication is available on CD-ROM and must be purchased. (Tip: Search publications page for "DGWS.")

Stuebinger, L.A., and Elphingstone, G.M., Jr., "Multipurpose Wells: Downhole Oil/Water Separation in the Future," SPE 65071 (revised SPE 49050 originally presented at the 1998 SPE Annual Technical Conference and Exhibition, New Orleans, LA, September 27-30, 1998)

Abstract: Promising new technologies are being advanced to reshape development strategies in your fields. It is not always necessary to dedicate wells to production or injection; now, both functions can be performed within one multipurpose wellbore. Technologies exist to reduce water-handling volumes at the surface by keeping the water downhole.

The discovery of downhole oil, water, and gas gravity segregation in the wellbore and the ability to keep fluids separated makes it possible to generate revenue from a wellbore at the same time that it is injecting or disposing water. This paper will discuss:

> design and testing at the Rocky Mountain Oilfield Testing Center of the first downhole oil-water separation artificial lift system to utilize downhole gravity segregation;
>
> evolving modeling procedures;

superior environmental performance;

impediments to deploying radically new technologies; and

a vision of the future.

Shaw, C., "Downhole Separation as a Strategic Water and Environmental Management Tool," SPE 61186 presented at the SPE International Conference on Health, Safety, and the Environment in Oil and Gas Exploration and Production, Stavanger, Norway, June 26-28, 2000

Abstract: A large number of North Sea fields have been in production for many years, have matured and reached a plateau in total liquids production. The plateau is often a function of water processing constraints that limit the ultimate production rate. This total production rate often remains constant while the oil production rate declines, resulting in production of water far exceeding that of the oil. When this is applied over a number a fields it can quickly be determined that total discharges of water to the environment are increasing rapidly (Refer to Fig.1). The environmental impact of handling, treating and disposing of this water is a major headache and is testing the industry's ingenuity to come up with viable, sustainable alternatives to discharge. Pressure is also being applied by legislative bodies to limit the residual hydrocarbon content. As signatories to the Oslo Paris Convention, the UK Government agreed (on a trial and voluntary basis) with industry to a maximum oil residual of 30 mg/l for discharges on the UKCS. In the light of ever increasing discharge levels (tonnes/yr), it would not be surprising if additional qualities become legislated (e.g. COD and certain transition metal ion content etc.). Indeed, the potential banning of produced water discharges to the environment cannot be dismissed.

Wellbore separation and same-well disposal is fast becoming accepted by operators as an environmentally friendly tool that provides a unique opportunity to reduce operating costs and enhance the economic viability of higher water-cut wells (>65%), while simultaneously reducing the risk of pollution. The technology is inherently a low-risk approach as there is no adverse affect on well productivity, and tried and tested componentry is employed. It is expected that with time this technology will be considered as just another viable water management tool and will compete directly with shutoff technologies in the strategic handling of produced water.

The Downhole Oil-Water Separator (DOWS) system is able to produce oil to the surface while simultaneously disposing of water into a zone accessible from the same wellbore. This substantially reduces the environmental risk associated with (1) spills and leaks at the surface, (2) subsurface contamination of aquifers during casing failure in production and re-injection wells, (3) chemicals used to treat the produced water and (4) disposal levels.

The DOWS system has been developed using proven technology. Hydrocyclones, Electric Submersible Pumps (ESPs) and conventional completion equipment are all individually available off the shelf. This greatly reduces the technical risk thereby enabling operators to reach their financial goals via reduced operating costs, increased oil production and even increased

recoverable reserves while simultaneously meeting their commitment to the environmental. Long term targets to reduce overall disposal and emission levels can be met.

This paper will focus on the Health, Safety and Environment issues associated with DOWS. It is intended to show that operators, through use of DOWS technology, will be able to handle the ever increasing water levels, while still hitting economic targets and simultaneously making tremendous strides towards the ultimate environmental goal of zero discharge.

Veil, J.A., et al, "Feasibility Evaluation of Downhole Oil/Water Separator (DOWS) Technology," Argonne National Laboratory Fossil Energy Technology Feasibility Study prepared for the U.S. DOE (January 1999)

This report provides an excellent overview of DOWS technology through 1998. The authors provide a description of DOWS technology, an analysis of DOWS installations and field trials, and a discussion of regulatory considerations. The authors conclude that DOWS technology needs further improvement, but has great potential to save money and reduce environmental impacts of managing produced water at the surface. This report is available on the Argonne National Laboratory's web site at http://www.ead.anl.gov/pub/dsp_detail.cfm?PubID=416.

Veil, J.A., et al, "Downhole Oil/Water Separators: An Emerging Produced Water Disposal Technology," SPE 52703 presented at the 1999 SPE/EPA Exploration and Production Environmental Conference, Austin, TX, February 28-March 3, 1999

This 1999 paper on the subject provides a synopsis of downhole oil-water separation (DOWS) technology. The authors describe the types DOWS developed and installed at the time and discuss problems experienced in DOWS installations. The authors also provide a brief discussion of regulatory issues related to the use of DOWS.

Shaw, C., and Fox, M., "Economics of Downhole Oil-Water Separation: A Case History and Implications for the North Sea," SPE 50618 presented at the SPE European Petroleum Conference, The Hague, The Netherlands, 20-22 October 20-22, 1998

Abstract: This paper describes a system used for the separation of oil and water in the far reaches of the wellbore where the separated produced water is re-injected into a zone accessible from the same wellbore. Successful application of this technology in low risk wells has been achieved and documented. Risk is defined here as a function of workover cost and deferred oil production: high risk therefore being a prolific well with high workover costs. Application of this separation technology in high risk wells can only occur when the issues of the technology, cost, and reliability have been defined. The more sophisticated completions that will be required for high risk wells will be more reliable. while the prolific nature of the wells gives a rapid return on the investment.

This paper outlines the factors that make up the economic decision whether to install such a system and, using a low risk case history, demonstrates the favorable economics of installing a separator system in a given application. Using the low risk example. it is shown how the ideas can be extrapolated to a typical North sea well where. although higher risk. the potential reward is also far higher.

Tubel, P., and Herbert, Roger P., "Intelligent System for Monitoring and Control of Downhole Oil Water Separation Applications," SPE 49186 presented at the SPE Annual Technical Conference and Exhibition, New Orleans, LA, 27-30 September 27-30, 1998

Abstract: This paper describes an intelligent system used to monitor and control the separation of oil from water downhole with simultaneous re-injection of the water into a zone accessible from the same wellbore. The paper outlines the individual technologies that make up the system, describes how the technologies are assembled in the wellbore, and indicates what requirements the system has of the wellbore. The paper provides a description of an intelligent system that significantly reduces water produced from a borehole while potentially increasing oil production. The paper describes the control of water flow into an injection zone and the increase in efficiency of a pump system by utilizing downhole instrumentation and intelligent systems for monitoring and control of the oil/water separation process. The intelligent system is composed of an artificial lift system, permanently deployed instrumentation for fluid and equipment monitoring, completion hardware based on an electric tubing-to-tubing choke valve, and a hydrocyclone-based oil/water separator.

Stuebinger, L.A., and Elphingstone, G.M., Jr., "Multipurpose Wells: Downhole Oil/Water Separation in Your Future," SPE 49050 presented at the 1998 SPE Annual Technical Conference and Exhibition, New Orleans, LA, September 27-30, 1998

Abstract: Promising new technologies that are being advanced have the potential to reshape development strategies in your fields. It is not always necessary to dedicate wells to production or injection; now, both functions can be performed within one multipurpose wellbore. Technologies exist to reduce water-handling volumes at the surface by keeping the water downhole.
The discovery of downhole oil, water, and gas gravity segregation in the wellbore and the ability to keep fluids separated makes it possible to generate revenue from a wellbore at the same time that it is injecting or disposing water. This paper will discuss:

- Design and testing at the Rocky Mountain Oilfield Testing Center of the first Downhole Oil Water Separation (DOWS) artificial lift system to utilize downhole gravity segregation
- Evolving modeling procedures
- Superior environmental performance
- Impediments to deploying radically new technologies
- A vision of the future

Tyler, M.R., "Texaco Dual Action Pumping System," Project Test Results, Rocky Mountain Oilfield Testing Center, http://www.RMOTC.com/Library/Test_Reports.html (March 16, 1998)

Texaco successfully tested a dual action pumping system (DAPS) for downhole oil water separation and injection. The DAPS separates water from the oil in the casing-tube annulus and injects most of the water into a lower formation while lifting the oil and remaining water to the surface. A distinguishing characteristic of DAPS is that it consists of coupled rod pumps with two vertically separated intakes. The DAPS was the first artificial lift technology to employ downhole oil, water, and gas gravity segregation to minimize the amount of water lifted to the surface (by injecting most of it downhole) while producing all oil and gas to the surface. As oil production declines in the well the water production increases. The lifting cost per barrel of oil can be reduced if less water is produced to the surface. The test showed that the DAPS can reduce the amount of produced water disposed of at the surface, increase revenue in wells constrained by lift capacity, and lower operating expenses and lifting costs.

Loginov, A., and Shaw, C. "Completion Design for Downhole Water and Oil Separation and Invert Coning ," SPE 38829 presented at the 1997 SPE Annual Technical Conference and Exhibition, San Antonio, Texas, October 5-8, 1997

Abstract: Wellbore separation is becoming increasingly viable as the process becomes more accepted and completion designs become more standardized. Successful wellbore separation has been achieved with same-well clean water disposal using a combination of downhole pump and hydrocyclones. Gravity wellbore separation, often referred to as "suppressed coning," also has been demonstrated where the oil and water components have been produced separately and where gas/water or oil/water separation has been adequately achieved using the retention time available in the well annulus.

Downhole separation and injection also is becoming more attractive as its benefits generate improved Net Present Value through earlier production, and increased recoverability by extending the life of the well and affecting water flood patterns and pressure maintenance.
This paper addresses some of the problems related to downhole separation with respect to the completion design, and suggests design concepts developed to overcome some of these problems.

Stuebinger, L., et al, "Dual Injection and Lifting Systems: Rod Pumps," SPE 38790 presented at the SPE Annual Technical Conference and Exhibition, San Antonio, TX, October 5-8, 1997

Abstract: In 1994 Texaco personnel viewed chemicals as the primary means to reduce water handling costs. They recognized from downhole videos that oil and water remain separated in the tubing-casing annulus. Capitalizing on this revelation of "gravity segregation," they conceptualized a dual-ported, dual plunger rod pump to produce oil and water from the annulus on the upstroke while injecting water on the downstroke. Texaco and Dresser jointly developed

this pump and named it the Dual Action Pumping System (DAPS). In January 1995, the first generation prototype was installed. It verified the technical and economic feasibility of this new technology. It substantially increased production while simultaneously reducing power requirements. A second generation prototype was developed to improve the valve design. It has continued to function without problems since its installation in October 1995. Tests in a Rocky Mountain Oilfield Testing Center well and several Talisman wells have further demonstrated that this will be a unique, new tool for the oil industry. This paper will both explain how DAPS works and describe some of the early testing results. Work is continuing to improve the performance predictions. Tests have shown it to be an inexpensive technology that can reduce lifting costs and thereby increase and/or accelerate reserves recovery when the right conditions exist. While many potential applications or benefits of DAPS have been identified, these can generally be classified in three categories:

- Increase oil production
- Reduce water handling costs
- Reduce potential investment costs

Matthews, C.M., et al, "Application of Downhole Oil/Water Separation Systems in the Alliance Field," SPE 35817 presented at the Third International Conference on Health, Safety & Environment in Oil & Gas Exploration & Production, New Orleans, Louisiana, June 9-12, 1996

The authors provide a detailed discussion of one of the first field applications of downhole oil-water separation (DOWS) where separated water is injected in a disposal zone in the producing well. The project was conducted in a field in Alberta, Canada, and addressed circumstances specific to the field. The DOWS systems used in the field test were a combination of hydrocyclones and electrical submersible pumps, progressive cavity pumps, and rod (beam) pumps. The main objective of the field tests was to demonstrate the operation and prove the economic benefits of the respective separation systems. The research and development project also addressed the economic feasibility modeling to assess the implementation of the technology in different fields. The authors also describe the problems encountered with the DOWS systems.

The test results were favorable in that the quantity of water produced to the surface was reduced an order of magnitude reduction with no decrease in oil production rates. In fact, three of the test wells experienced an increase in oil production. The authors conclude that the technology has the potential to significantly increase the recovery of the original oil in place by making it economical to produce fields longer in spite of increased water influx.

Kjos, T., et al, "Down-Hole Water-Oil Separation and Water Reinjection Through Well Branches," SPE 30518 presented at the 1995 SPE Annual Meeting, Dallas, Texas, October 22-25, 1995

The authors discuss alternative well configurations incorporating downhole separation of oil and water (DOWS), associated costs, feasibility, and an evaluation of the effects of downhole separation on well flow performance and reservoir behavior. The discussion specifically addresses produced water treatment and management on offshore production platforms. The authors offer only suggested downhole separation equipment and configurations. No actual field applications are presented. The downhole separation device preferred by the authors is the hydrocyclone. The authors also observe that because DOWS reduces the quantity of produced water managed at the surface, the quantity of necessary treatment chemicals (e.g., hydrate and corrosion inhibitors) is also reduced.

The authors also discuss the combination of DOWS with dual completions in oil and water zones to control coning. They conclude that balancing of the water-oil contact is possible by dual completion. And, by reinjection of the produced water far away from the production interval, the water displacement mechanism can be maintained. By supplementing the produced water reinjection by external water, in order to enhance the water displacement, very high oil recoveries may be obtained.

Grubb, A.D., and Duvall, D.K., "Disposal Tool Technology Extends Gas Well Life and Enhances Profits," SPE 24796 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum engineers, Washington, DC, October 4-7, 1992

The authors, of OXY USA, describe the application of a saltwater disposal tool, called a Seating Nipple Bypass which is compatible with equipment currently installed on many gas wells. The system allows produced water to be conventionally pumped up the tubing string and then gravity fed to a disposal zone below the producing interval. (Note that it is necessary to have a permeable disposal zone that will take fluid under hydrostatic head.) Therefore, the use of the tool is specifically applicable to marginal gas wells that are not close to a disposal system. Water is not handled at the surface, which eliminates associated waste generation and environmental problems. Because produced water does not have to be disposed at the surface, disposal costs (e.g., trucking and commercial disposal wells) are eliminated. In the field application described by the authors, this resulted in a significant reduction in operating expense, which allowed several wells to continue to produce rather than be abandoned. The authors provide the economics of the project, as well as a detailed description of the downhole water disposal tool, its installation, and its operation. This paper provides a great waste minimization technique that may allow increased reserve recovery simply by reducing the disposal expense and prolonging the economic life of a marginal gas well.

Treating Produced Water To Reduce Associated Waste

See also "Produced Water" under "Recycling Production Wastes."

Romaine, J., et al, "Long Term Use of Oxidizing Agents in Utah Salt Water Disposal Results in Increased Injection Rates and Reduced Operating Costs," SPE/DOE 35368 presented at the 1996 SPE/DOE Tenth Symposium on Improved Oil Recovery, Tulsa, Oklahoma, April 21-24, 1996

The author describes how chlorine dioxide was used to eliminate the harmful effects of bacteria and sulfide sludge on the performance of waterflood injection disposal systems. Chlorine dioxide was substituted for quaternary amine biocides for control of sulfate-reducing bacteria. The paper includes a description of the water and injection system, the chlorine dioxide generator, and the treatment procedures. The chlorine dioxide treatment eliminated the need to acidize lines and wells and the manual removal of biomass and sulfidic pads from tanks. As a result, the field's operating expenses were reduced substantially. Documented savings of $1.72MM over four years were attributed to reduction of electricity usage (less power required due to lower injection pressures), avoided sludge disposal costs, and elimination of acidizing jobs. This change in procedure resulted in significant waste minimization, and operators experiencing similar problems may consider this solution.

The author references the following papers, which provide further discussion on the use of chlorine dioxide for sulfide and sludge control.

> Romaine, J, et al, "Application of Chlorine Dioxide as an Oilfield Facilities Treatment Fluid," SPE 29017 presented at the SPE International Symposium on Oilfield Chemistry, San Antonio, Texas, February 14-17, 1995
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> McCafferty, J.F., et al, "Field Performance in the Practical Application of Chlorine Dioxide as a Stimulation Enhancement Fluid," SPE 20626, *SPE Production & Facilities* (February 1993) 9-14

3.10 PRODUCT SUBSTITUTION IN PRODUCTION OPERATIONS

Lovell, D., and Pakulski, M., "Hydrate Inhibition in Gas Wells Treated With Two Low Dosage Hydrate Inhibitors," SPE 75668 presented at the SPE Gas Technology Symposium, Calgary, Alberta, Canada, April 30-May 2, 2002

This paper describes a treatment to control gas hydrate formation in gas wells, which offers an alternative to methanol and other solvents ("thermodynamic inhibitors). In particular, methanol may be costly. Also, storing and using methanol creates the potential for hazardous waste generation. The authors provide a substantive discussion of the alternative treatment using antiagglomerant (AA) and kinetic inhibitor (KI). These inhibitors are non-thermodynamic and inhibit hydrate formation by coating and commingling with hydrate nuclei to interfere with its growth and agglomeration. The authors discuss their chemistry and function in inhibiting

hydrate formation. Also, the authors note that these inhibitors are much less toxic than methanol and other solvents used for hydrate inhibition. The paper includes case studies of the successful and cost-effective use of AA and KI in gas wells in Canada.

See Pipeline Product Substitution in Section 5 for other papers which address new less-toxic hydrate inhibitors.

Brezinski, M.M., "New Environmental Options for Corrosion Inhibitor Intensifiers," SPE 52707 presented at the 1999 SPE/EPA Exploration and Production Environmental Conference, Austin, TX, February 28-March 3, 1999

The author describes an alternative to conventional corrosion inhibitor intensifiers that are necessary when conducting acid well stimulations. According to the author, the substitute intensifier is less toxic than copper- or antimony-based intensifiers and provides equivalent, or better, performance. In addition, the author claims that the new intensifier can also reduce the amount of corrosion inhibitor concentration under certain conditions. The substitute intensifier is a combination of formic acid and potassium iodide. The author explains the chemistry of the substitute intensifier and provides results of tests.

O'Neill, J.E., and Hill, D.G., "Reduction of Risk to the Marine Environment from Oilfield Chemicals – Balancing Environmental and Technical Needs," SPE 35946 presented at the International Conference on Health, Safety & Environment, New Orleans, Louisiana, June 9-12, 1996

See Section 2, "Drilling Operations" for the summary of this good paper on product substitution, process improvement, and "on-the-fly" mixing.

Paul, J.M., and Fieler, E.R., "A New Solvent for Oilfield Scales," SPE 24847 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, DC, October 4-7, 1992

Mobile has developed a new solvent to dissolve oilfield scales, including sulfates of barium, strontium and calcium, as well as calcium carbonate. Naturally occurring radioactive material (NORM) which is usually co-precipitated with barium and strontium sulfates is removed by this solvent. Performance features of the solvent and case histories of field tests are reviewed. Materials compatibility with the solvent and disposal options are also briefly discussed. While use of the solvent could be considered "treatment," waste minimization is accomplished if the amount of scale that must be handled as a waste is reduced.

Haslegrave, J.A., et al, "The Development of Corrosion Inhibitors With Low-Environmental Toxicity," SPE 24846 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington D.C., October 4-7, 1992

The authors, of Exxon Chemical, Ltd., discuss their toxicity testing of existing (circa 1992) corrosion inhibitors and their development of two new, less toxic active corrosion inhibitor chemicals. The authors do not provide any detail regarding chemical compositions of inhibitors other than to note that current inhibitors are "commonly encountered chemistries such as water soluble amines and imidazolines…" As of 2002, other chemical companies have surely developed other less toxic corrosion inhibitors.

Samuelson, M.L., "Alternates to Aromatics for Solvency of Organic Deposits," SPE 23816 presented at the SPE International Symposium on Formation Damage Control, Lafayette, LA, February 26-27, 1992

The author, of Dowell Schlumberger, describes a laboratory investigation to identify alternate solvent systems for the removal of near well bore organic deposits. The investigation found several alternative solvents which can replace aromatics solvents such as xylene and toluene. The alternative solvents can effectively remove paraffin, asphaltene, and pipe dope deposits. The author does not specify the components of the alternative solvents, but focuses on the investigative laboratory methods and theoretical solvency parameter comparisons linked to a database search. Although, toluene and xylene would be exempt from hazardous waste regulation if returned from the well bore, the use of less toxic alternative solvents remains a desirable waste minimization goal.

Himes, R.E., et al, "Environmentally Safe Temporary Clay Stabilizer for Use in Well Service Fluids," SPE 21604 presented at the International Technical Meeting of the Petroleum Society of CIM and the Society of Petroleum Engineers, Calgary, Canada, June 10-13, 1990

This paper discusses the advantages of organic clay stabilizers (OCS) over the traditional salt solutions (KCL, etc.). Specifically, OCS (organic cations) are equally effective, if not better, in stabilizing clays, but offer additional benefits including: 1) OCS can be used in liquid form and injected on-the-fly, eliminating the need for premixing salt water and leftover saltwater disposal; 2) OCS solutions at the recommended usage concentrations are nontoxic, biodegradable, and contain much less chloride than comparable salt solutions; and 3) the OCS liquid concentrate has been found to be more easily handled and more convenient to store than sacked salts. The author notes that OCS have been successfully used in numerous fracturing treatments. A case history documenting the use of OCS is included.

3.11 RECYCLING PRODUCTION WASTES

Various Wastes

Williams, R.L. and Harris, A., "Use of Scrubber Waste as an Oxygen Scavenger in Thermal Water Plant Operations," SPE 16368 presented at the SPE California Regional Meeting, Ventura, California, April 8-10, 1987.

This paper offers an excellent example of reuse of a waste and an early effort at waste minimization. The oxygen is scavenged from boiler feed water in steam flood operation with a high rate of 15,000 bwpd.

Recycling Produced Water

Erskine, D.W. et al, "Use of Produced Water for Oil and Gas Drilling in the San Juan Basin," Proceedings of the 9th International Petroleum Environmental Conference, Albuquerque, NM, October 22-25, 2002

The authors present the results of their study of the possibility of using produced water to build drilling mud. A primary issue was the potential of higher salinity produced water to negatively impact the quality of usable groundwater while drilling through aquifers. The authors provide a basic discussion of the principles of ground water flow and a description of the San Juan Basis hydrology. They explain how osmotic pressure (between mud and fresh formation water) and the effects of and molecular and advective diffusion result in rapid dilution of aquifer water to drinking water quality in the near vicinity of a borehole. The authors indicate that 10,000 ppm TDS produced water is the basis for their calculations and conclusions. This paper provides good background information for an operator interested in using produced water in drilling mud. Obviously, using produced water (which is plentiful) to make up drilling muds reduces the need to use fresh water sources. Lower TDS produced water is available in many producing areas.

Myers, J.E., et al, "An Evaluation of the Department of Energy Naval Petroleum Reserve No. 3 Produced Water Bio-Treatment Facility," SPE 66522 presented at the SPE/EPA Exploration and Production Environmental Conference, San Antonio, TX, February 26-28, 2001

This paper describes the design and operation of a bio-treatment (wetland) facility for produced water in Wyoming. The purpose of the project was to replace disposal well operations, to reduce produced water management costs, and to discharge water which is beneficial to wildlife. The described facility is successfully operated, in part because the concentration of total dissolved solids in the produced water is low enough to meet NPDES permit requirements. Otherwise the treatment system is shown to be effective in reducing organic and inorganic contaminants in the water. For example, benzene concentration was effectively eliminated by the treatment. The authors provide a thorough description of the treatment systems design and the sampling and analysis performed to document its effectiveness. The authors state that the

system is saving $17,000 per year on utilities. This type of produced water treatment may not be feasible in certain producing areas; however, limited applications may be identified. High salinity and NPDES permitting for discharge of treated water would be primary concerns.

Bradley, R., "New Gas Well Produced Water Treatment Protects the Environment and Saves Money," Proceedings of the 6th International Petroleum Environmental Conference, Houston, TX, November 16-18, 1999

The author describes an treatment and desalination system for water produced with coal bed methane. The system, called High Efficiency Reverse Osmosis (HERO™), is claimed to more effectively pretreat produced water prior to the RO unit. Concerns regarding water purification were scale, hardness, alkalinity, total dissolved solids, and silica. The author provides a detailed description of the weak acid cation resin pretreatment system and the RO unit. The system is claimed to be superior those using the normal strong acid cation resins. The author discusses the results of two field tests, which proved the system to be cost effective compared to transport and disposal in commercial Class II wells. The maximum TDS of treated produced water was about 20,000 mg/l, and the system's effluent was reduced to about 250 mg/l salinity. Although the described field tests were limited to relatively low-TDS water from coal bed methane production, this paper may be of interest to operators in other producing areas.

Doran, G.F., et al, "Evaluation of Technologies to Treat Oil Field Produced Water to Drinking Water or Reuse Quality," SPE 38830 presented at the 1997 SPE Annual Technical Conference and Exhibition, San Antonio, Texas, October 5-8, 1997

This paper describes ARCO Western Energy's research and planning for a 43,000 bpd produced water treatment system at the Placerita Field in California. ARCO researched various technologies for produced water demineralization which included: multi-stage flash distillation; multiple effect distillation; vapor compression; reverse osmosis; nanofiltration; and electrodialysis/electrodialysis reversal. ARCO selected reverse osmosis and mechanical vapor compression (MVC) for comparison. Reverse osmosis was selected because the capital costs were less than 40 % of MVC, the operating costs were less than 45% of MVC, and there is a greater acceptance of RO for drinking water applications. The 43,000 bpd RO treatment system was estimated to require an $11 million capital investment. The estimated annual operating cost (1996 dollars) was 13 cents to 18 cents per barrel of treated water (includes pretreatment and sludge disposal).

Note: Two subsequent SPE papers describing this project were published in 1998 and 1999. According to the abstract of the 1999 paper, the project has proceeded only to the construction, operation, and study of a pilot 10 gpm treatment unit.
The results of the pilot study did not significantly alter the conclusions of the paper discussed above regarding the 43,000 bpd RO plant.

Leong, L.Y.C., et al, "Developing a Cost Effective Environmental Solution for Produced Water and Creating a 'New' Water Resource," Proceedings of the 4th International Petroleum Environmental Conference, San Antonio, Texas, September 9-12, 1997

The authors describe a US DOE-sponsored pilot study to assess the technical and economic feasibility of treating produced water to 1996 California potable and reclaimed water standards. The process used warm precipitative softening and reverse osmosis to reduce salinity, silica, ammonia, boron, and organics levels in produced water from the Placerita Oil Field in Los Angeles County, California. The produced waters salinity was about 6,000 mg/L; therefore, the demonstrated technology is limited. However, the pilot study was successful in economically treating this low-salinity produced water to quality suitable for industrial use. The treated produced water was used as steam flood boiler feed water. The authors provide a fairly detailed description of the project technology and economics. This paper is a good resource for operators interested in produced water treatment technology for the purpose of reclaiming water for beneficial use.

This paper is available at http://ipec.utulsa.edu/.

Russell, C.S., and Hazlett, W.G., "Injection of Oilfield Produced Water into Water Aquifers – The Ojo Alamo Project," SPE 35876 presented at the International Conference on Health, Safety & Environment, New Orleans, Louisiana, June 9-12, 1996

The authors present an interesting concept for recycling produced water. They describe aquifer modeling which includes produced water injection and conclude that their study "shows that the injection of production water into the Ojo Alamo would not have a significant impact in the current water quality and will add to the present usable water supply." Note that the modeling considers produced water with 10,000 ppm TDS. It is not clear that this technique could be applied elsewhere, but merits consideration, considering pending water shortages. As the authors note, this technique would require EPA waivers of UIC regulatory requirements under the SDWA.

Tao, F.T., et al, "Conversion of Oilfield Produced Water Into an Irrigation/Drinking Quality Water," SPE 26003 presented at the SPE/EPA Exploration and Production Environmental Conference, San Antonio, Texas, March 7-10, 1993

The authors describe a system for treating produced water to a level satisfactory for injection into a drinking water quality aquifer. The treatment process consists of air flotation, clarification, softening, filtration, reverse osmosis (RO), and water reconditioning. A pilot plant was successfully operated for an extended period of time for handling water with approximately 7,000 mg/L of total dissolved solids, 250 mg/L silica, and 170 mg/L soluble oil at a wide range of pH (7-11). The quality of water met stringent California drinking water maximum contaminant Levels. The pilot plant operation, including its modifications and optimization lasted approximately two years. The paper includes detailed operating parameters and modifications that were made to make the system as efficient and cost effective as possible.

The authors focus on operating parameters which minimize fouling of the RO (can be quite expensive to replace). The authors state that the operating cost (including the chemicals, power, and membrane replacement) is $0.06-0.08 per barrel, and that the total investment cost for a full size 50,000 barrel per day plant is estimated at $7 to 9 million dollars.

This project may be useful to an operator who generates similar produced water and can justify the economics of installing and operating such a treatment system. Such a project would be beneficial in areas experiencing drought conditions.

Jan, R.J., and Reed, T.G., "A New Caustic Process for Softening Produced Water for Steam Generation," SPE 19759, *SPE Production Engineering* (May 1992) 199-202

This paper describes the various systems for softening produced water for use as boiler feed in steam flood EOR. The authors describe the processes and limitations (e.g., ability to remove silica) of the following systems: 1) ion exchange (combinations of various strength acid resins); 3) lime-soda followed by ion exchange; and 3) Thermosoft/Thermosludge. The authors explain how they decided on an caustic precipitation system with weak-acid ion exchange polishing for use in Mobil E&P's Belridge Field in Kern County, CA. The field's produced water had 10,500 TDS. The selected system performed well and at relatively lower cost (includes reduced waste management problems), and the system allowed 100% use of produced water for feed. The authors state, "For produced waters with even higher hardness and TDS than those of Belridge, the process would be even more attractive than the weak acid followed by weak acid in terms of capital and operating costs." This paper is an excellent reference for those conducting or considering steam flood EOR.

Thomas, S.A., Yost, M.E., and Cathey, S.R., "Silica Removal From Steamflood-Produced Water: South Texas Tar Sands Pilot," SPE 13021, *SPE Production Engineering* (May 1987) 131-136

This paper is a bit dated, but describes a hot-lime precipitation system which reduced silica in produced water from above 400 mg/l to below 50 mg/l – adequate for use as boiler feed water. The field test resulted in plans to license a 50,000 bpd water treatment process for the Saner Ranch property operated by Conoco (Maverick Co., TX). The system allowed the operator to discontinue use of relatively fresh water from an aquifer and reduced produced water disposal.

Of interest, the authors referenced "Wet Steam Generator Quality Guidelines" (API Recommended Practice No. 1IT, Appendix A, March 1983), which specifies TDS less than 30,000 mg/l. The authors of SPE 19759 (above) stressed the need to reduce TDS to much lower levels. The authors of this paper do not address TDS.

Reyes, R.B., "Softening of Oilfield Produced Water by Ion Exchange for Alkaline Flooding and Steamflooding," SPE 11706 presented at the 1983 California Regional Meeting, Ventura, California, March 23-25, 1983

The author describes the various ion exchange processes for reducing produced water TDS and hardness. This paper is a bit dated and should be read along with SPE 19759.

Brine Completion Fluids

Foxenberg, W.E., et al, "Optimizing the Quality of High Density Brines for Maximum Performance and Economic Value," SPE 24784 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, DC, October 4-7, 1992

This paper provides guidelines for restoring used brines to new brine standards by addressing both physical and chemical contaminants. Laboratory procedures and operational guidelines are provided that establish methods for identifying problematic contaminants and simulate the brine specific reclamation techniques and field application requirements. Standards for restoring used brines to new/non-damaging compositions are also provided.

McIntyre, J.A., et al, "Novel Breaker/Filtration Process Reduces the Cost of Recycling Viscosified Brine Completion Fluids," SPE 17461 *SPE Production Engineering* (November 1990) 469-474

This paper describes a novel process for recycling polysaccharide-viscosified brine completion fluids. The process uses oxidants generated directly in the used brine by electrolysis to "break" the viscosity. The treated brines can be filtered with conventional equipment, reviscosified, and reused. The process has been applied on a laboratory scale to Br-/Cl- brines containing Na+, K+, Ca+2, and Zn+2 cations. Calculations with information from pilot-scale tests on NaBr/NaCl brines indicate that the process should be attractive economically.

3.12 ROD-PUMPS AND TUBING

Palmour, H.H., "New Technology to Protect the Environment When Sealing Fluids or Gases Under Pressure," Proceedings of the 9th International Petroleum Environmental Conference, Albuquerque, NM, October 22-25, 2002

This paper describes a stuffing box designed to eliminate fugitive emissions of pumped fluids. The stuffing box employs two seals and a sacrificial lubricant. The sacrificial lubricant, which is intended to be environmentally benign, is pressurized by the pumped fluid and is the only fluid which may be released. The author cites tests of the stuffing box on rod-pumped wells at the Rocky Mountain Oilfield Testing Center (RMOTC). RMOTC testers concluded that the stuffing box was effective in reducing leaks and improving efficiency (i.e., energy savings). This design

may be useful for rod-pumped wells, but also is indicated to be adaptable to other types of pumps (e.g., triplex, plunger, and progressing cavity pumps). Successful application of the described stuffing box should reduce the generation of waste crude oil and crude oil-contaminated soil.

This paper is available at http://ipec.utulsa.edu/.

Giangiacomo, L.A., and Hill, D.R., "Optimizing Well Efficiency With Smart Fluid-Level Controller Technology," SPE 52210 presented at the 1999 SPE Mid-Continent Operations Symposium, Oklahoma City, OK, March 28-31, 1999

The authors discuss the ongoing development of an improved fluid level controller, which can greatly improve the operating efficiency of rod-pumped wells (and wells with progressing cavity and electrical submersible pumps). The paper provides a through overview of well optimization using timers, pump-off controllers and echometers. The authors discuss how the new fluid level controller may be used in conjunction with remote telemetry to maximize well efficiency. The described fluid level controller will allow a well to avoid fluid pounding and pump at maximum efficiency almost at all times. Benefits include reduced pump wear and maintenance requirements, thus reducing waste generation. As well, the profitability of the well is improved.

Takacs, G, Improved Designs Reduce Sucker-Rod Pumping Costs," *Oil and Gas Journal* (October 7, 1996) 68-76

The author provides a thorough discussion of rod-pump design which optimizes operating efficiency and reduces electrical power costs. He describes the various energy losses and explains which losses can be minimized. Much of the authors discussion addresses means of improving lifting efficiency by optimizing the pumping mode. The author also discusses rod-string design and offers an alternative to using API specified designs. The author references the following technical paper which presents a method for rod-string design: Gault, R.H., and Takacs, G, "Improved Rod String Taper Design," SPE 20676 presented at the 65th SPE Annual Technical Conference and Exhibition, New Orleans, LA, September 23-26, 1990.

RMOTC, "D-JAX Pump-Off Controller, Project Test Results" RMOTC (April 4, 1995) This paper is available at the RMOTC Web Site: http://www.RMOTC.com/Library/Test_Reports.html

The D-JAX Pump-Off Controller (POC) is an electronic system attached to an oil well beam pumping unit. This project test report provides considerable detail regarding the D-JAX POC's installation and operation, as well as manufacturer information. The system measures the speed of the pumping unit, and will shut the pumping unit down when a speed increase is detected. The D-JAX POC micro-processor and software detects different levels of fluid pounding by monitoring time required for each stroke of the polish rod. Fluid pounding occurs when the pump does not fill completely on the upstroke. The speed increase is an indication of a "pump-off" condition. The D-JAX POC will shut down the pumping unit for a predetermined period

then restart the unit. The unit will run for a predetermined amount of time (i.e., 10 seconds). The speed will then be checked with every stroke and measured against the starting speed. The D-JAX POC will allow the unit to run until three consecutive strokes show a speed increase. Then the D-JAX POC will shut the unit down. The speed change is measured in milliseconds.

The RMOTC test found that the D-JAX POC performed favorably, reducing the operating time of the pumping units and decreasing the costs associated with electrical consumption and surface and downhole maintenance. The manufacturer states that the D-JAX POC provides:

- Unit shutdown when fluid entry is low.
- Indication of pump, failure.
- Indication of a hole in the tubing.
- Daily run time in hours and percentage.
- 30 day history of production run time.
- Daily reservoir management (instead of relying on physical testing data which may take weeks to obtain).
- Reduced manpower requirements.
- Reduced lost production due to inaccurate time clock settings.
- Reduced stuffing box failures and environmental cleanup expenses.
- Reduced surface and downhole repair and maintenance costs.

RMOTC, "Results of the V-Ger Lubricator System Test at the Rocky Mountain Oilfield Testing Center," Project Test Results," RMOTC, (1994) This paper is available at the RMOTC Web Site: http://www.RMOTC.com/Library/Test_Reports.html

The Rocky Mountain Oilfield Testing Center (RMOTC) tested the V-Ger Lubricator System in 1993 and 1994. The V-Ger lubricator applies a continuous flow of grease to the polish rod of a rod-pump. The unit is mounted above the stuffing box by a clamp that attaches to the walking beam. A chain connects the clamp to the ratchet arm of the V-GER lubricator. The arm operates a pump that propels the grease through a hose to the polish rod. The lubricator holds six pounds of grease which is continually applied to the polish rod at a rate determined by the operator. The RMOTC test results supported the manufacturer's claim that the V-Ger reduces heat damage; extends stuffing box packing life; protects the polish rod from electrolysis and corrosive production fluids; lessens the risk/frequency of stuffing box leaks; reduces labor requirements; and reduces electricity consumption. RMOTC's use of the V-Ger resulted in a confirmed electrical energy savings of 8%; a reduction of 36 man-hours per well; 50% less stuffing box repacking; all of which added up to a savings of $ 831.92 per year. RMOTC states that the V-Ger's initial investment should be recovered in about nine months.

Fleming, E.A., et al, "Overview of Production Engineering Aspects of Operating the Denver Unit CO_2 Flood," SPE 24157 presented at the SPE/DOE Eighth Symposium on Enhanced Oil Recovery, Tulsa, OK, April 22-24, 1992

This paper describes a CO_2 EOR flood operated by Shell Western E&P in West Texas. Also, the authors discuss equipment, artificial lift, and well control. The authors describe the use of a high pressure double pack stuffing box installed for pressure and well control. This double pack stuffing box is the Enviro-Pak high pressure pack-off, which the manufacturer claims provides protection from stuffing box leaks.

Lacy, R.D., "The Rotating Tubing Hangar System: A Unique New System Designed to Extend the Run Time of Rod Pumped Wells," SPE 23977 presented at the 1992 SPE Permian Basin Oil and Gas Recovery Conference, Midland, Texas, March 18-20, 1992

This paper discusses a technique in which the tubing life is extended on rod pumped wells (five to seven times normal run time). The paper describes the concept, development, and implementation of a new rotating tubing hangar system in detail. A technique was developed in which the tubing is rotated a small amount with each stroke of the pumping unit. This rotation prevents the formation of a groove from constant contact with the rod and greatly reduces the potential for tubing failure. The rotating tubing hangar is powered by the movement of the walking beam and requires no additional power source or additional energy. The paper gives four case histories which demonstrate the effectiveness of this technique in reducing the "pulling jobs" due to tubing failures. This is a waste minimization technique because the waste generated from a pulling job is eliminated, and operating costs are reduced. In one case history, the operator estimated that the 20 units installed in the field would result in a yearly operating cost reduction of $100,000. Also, the author asserts that the system can be effective in reducing problems caused by paraffin build-up, resulting in extended pumping time and additional savings in operating expenses. In one case history, the rotating tubing hangar system resulted in reduced paraffin treatments.

Matthews, C.M., and Dunn, L.J., "Drilling and Production Practices To Mitigate Sucker-Rod/Tubing-Wear-Related Failures in Directional Wells," SPE 22852, SPE Production & Facilities (November 1993) 251-259

The authors discuss the effects of well bore geometry and production operating parameters on rod and tubing wear in deviated and slant wells. The study that resulted in the authors observations, conclusions, and recommendations was conducted in a heavy oil-producing field in Canada. Most wells in the study used progressive cavity pumping systems, but a few used conventional rod pumps. The authors provide a fairly detailed discussion of the study results. The authors' recommendations regarding the control of well geometry when drilling and operational practices may be helpful to operators in any area who are experiencing excessive rod and tubing wear in deviated wells.

3.13 WELL PRODUCTION AND STIMULATION

Also *see* "Well Completions" in Section 2 for references related to:

Casing and Tubing

Using A Snubbing Unit

Cementing

Blast Furnace Slag Mud Converted to Cement as an Alternative

Mixing Fracturing Fluids and Cement On-The Fly

Using Coiled Tubing

Coiled tubing (CT) technology has advanced over the years. CT has been proven to be an effective way to sidetrack a well through tubing (however, most applications appear to have been through 4.5 inch or greater tubing). As well, CT has been used for well stimulation and workover operations. CT tools are continually being improved. In general, the use of CT can reduce the overall quantity of waste generated by a well stimulation or well workover operation. The following technical papers and articles are selected to illustrate the feasibility and advantages of CT (some are included without annotation). Please note that there are numerous technical papers (e.g., Society of Petroleum Engineers), which discuss the use of CT in many different applications. Also, numerous papers and articles address specific CT technologies such as bits, CT materials (e.g., composite CT), CT fatigue analysis, and specialized tools. An operator interested in investigating the use of CT should conduct further research.

Also *see* Section 2, "Drilling and Completion Operations," for additional technical papers and articles addressing the use of coiled tubing.

Adams, L.S., and Overstreet, C.C., "Coiled Tubing Facilitates Deep Underbalanced Workover," *Oil and Gas Journal* (March 31, 1997) 64-69

This article describes the use of coiled tubing to perform a through-tubing scale removal procedure in a 22,600-foot low-pressure, high-temperature gas well in West Texas. The authors describe the risk analysis used to determine the best workover option for the problem and the design and implementation of the coiled tubing procedure. The cited advantages of using coiled tubing for the workover included: no kill fluid; reduced tubular trip time, and reduced costs. In particular risk and workover costs were greatly reduced. The procedure reduced waste generation associated with a conventional workover rig (which requires pulling tubing and using kill fluid, as well as improving production.

Soetedja, V, and Hunter, D.L., "Production Optimizing With Coiled Tubing and Other Rigless Techniques," SPE 36963 presented at the 1996 SPE Asia Pacific Oil and Gas Conference, Adelade, Australia, October 28-31, 1996

The authors present case histories of the use of coiled tubing in well workovers. Examples include setting cement packers and using oriented perforating through tubing. According to the authors, the use of coiled tubing workovers resulted in oil and gas production increases and resulted in significant savings compared to conventional rig supported workovers. In one case history, a cement plug was placed to successfully shut off water. This paper provides an excellent example of coiled tubing use in workovers.

Stephens, R.K., et al, "Lessons Learned on Coiled Tubing Completions," SPE 35590 presented at the SPE Western Regional Meeting, Anchorage, AK, May 22-24, 1996

The authors discuss various completions techniques developed for use in wells on the North Slope of Alaska. They explain the problems encountered, lessons learned, and how the procedures were improved. The paper provides a detailed discussion of the various procedures (which include gas and water shutoff techniques). Although this paper discusses the use of coiled tubing for completions is in Alaska, it may be useful for a person considering similar applications in other areas.

Loveland, K.R., and Bond, A.J., "Recent Applications of Coiled Tubing in Remedial Wellwork at Prudhoe Bay," SPE 35587 presented at the SPE Western Regional Meeting, Anchorage, AK, May 22-24, 1996

This paper is a "companion" to SPE 35590 in that it describes the use of coiled tubing for remedial well workovers. Application discussed include reservoir surveillance, capacity sustainment (e.g., stimulations), gas and water shutoffs, injection control, and mechanical repairs. The authors indicate that coiled tubing can be successfully used for remedial work.

Courville, P.W., and Clark, T.R., "Coiled Tubing Completions: An Economic Discussion of Procedures," SPE 29781 presented at the 1995 SPE Middle East Oil Technical Conference and Exhibition, Bahrain, March 11-14, 1995

This paper discusses the evaluation method for coiled tubing completions in relatively low bottom-hole pressure wells in a non-hostile environment. The discussion concentrates on the use of electric submersible pumps and gas lift methods. The authors note that if coiled tubing were used for both underbalanced drilling and completion, a well might not ever be killed by brine. Also, they note that coiled tubing is cleaner than jointed pipe in that pipe dope is not required for connections.

Adams, L.S., and Smith, L.W., "An Evaluation of Large Diameter Coiled Tubing for Subsurface Production Tubulars," SPE 29456 presented at the Production Operations Symposium, Oklahoma City, OK, April 2-4, 1995

The authors provide an explanation of the use of coiled tubing in lieu of threaded tubulars for production applications. Specifically, they address the economics and provide examples, and they present a "future perspective." At the time of the presentation (April, 1995), the authors noted that the economic use of coiled production tubing within onshore wells was marginal. The authors also noted certain waste minimization aspects to the use of coiled tubing including: elimination of the need for kill fluid; elimination of spills associated with kill fluids; reduced well tubing repair; reduced corrosion points; and reduced use of pipe dope.

Nirider, H.L., et al, "Coiled Tubing as Initial Production Tubing: An Overview of Case Histories," SPE 29188 presented at the 1994 Eastern Regional Conference & Exhibition, Charleston, WV, November 8-10, 1994

Walker, E.J., et al, "A Spoolable Coiled-Tubing Gas-Lift Completion System," SPE 26538 presented at the 68th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Houston, TX, October 3-6, 1993

This paper describes an early, successful gas-lift completion using coiled tubing with spoolable gas lift valves. The completion was in a well on the North Slope of Alaska.

Pleasants, C.W., et al, "Design, Testing, and Field Use of a New Selective Reeled Tubing Well Stimulation System," SPE 22826 presented at the 66th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Dallas, TX, October 6-9, 1991

This paper describes the development of a workover procedure using coiled, or reeled, tubing with new downhole tools designed specifically for use with the coiled tubing. The new tools allow through tubing workovers that meet the demands of high-pressure formation stimulation. A mechanical, positive, selective, sealing and isolation system is created. Well components are effectively isolated and protected from stimulation fluids (e.g., acids) and pressure. Case histories of successful application in the field are presented. The use of this procedure offers several advantages over conventional workovers using workover rigs, including speed, continuous circulation, and live well servicing. An important benefit is the reduction in the volume of generated workover wastes (e.g., rig wastes are eliminated and kill fluids are not required).

Coronado, M.P., et al, "Thru-Tubing Inflatable Workover Systems," SPE 22825 presented at the 66th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Dallas, TX, October 6-9, 1991

An alternative procedure for well workovers is presented in this paper. The use of coiled tubing or wireline with inflatable packing elements allows the servicing of wells without the use of conventional workover rigs and eliminates the need for heavy weight kill fluids (which may cause formation damage). This alternative is now feasible because of recent advances in inflatable packing element design. Tools have been designed to work with the coiled tubing or wireline through production tubing and in the production casing interval. Workovers that can be accomplished using the coiled tubing/wireline alternative include selective and zonal chemical treatments, temporary and permanent zone blankoff, production and injection flow profile modifications, and formation fracturing. This paper describes the technology and presents case histories of many of the cited applications. Benefits of using this workover procedure include reduced expense, reduced generation of workover wastes (e.g., from kill fluids and pulling tubing), and reduced potential for formation damage.

Slim Hole Completions

Kroell, E., and Spoerker, H.F., "Brief: Slimhole Completion and Production," SPE 37375, *Journal of Petroleum Technology* (September 1996) 846-847

The authors provide a comprehensive overview of the feasibility of slimhole completions and production. They address numerous issues and considerations, such as perforation systems, artificial lift, stimulation, and workovers. The paper also addresses production limitations of slimhole completions. The authors provide an excellent overview for any operator considering slimhole drilling and completion. (Note: This paper is derived from an earlier paper which provides more detail: Kroell, E., and Spoerker, H.F., "Slimhole Completion and Production – What To Do After We Drilled The Well," SPE/IADC 35129 presented at the SPE/IADC Drilling Conference, New Orleans, LA, March 12-15, 1996.)

Scale and NORM Control

Scale precipitation in downhole and surface equipment can cause the generation of additional waste, as well as cause operational problems. Naturally occurring radioactive materials (NORM) may be deposited as scale in certain fields, which causes an even more troublesome waste generation problem. There are many papers that offer various techniques to address this problem. For example, scale inhibitor formation squeezes have been proven effective. Several papers offer methods to optimize the effectiveness and life of scale inhibitor squeezes. As well as controlling scale, optimal squeeze life reduces the quantity of chemical that must be purchased and managed The following papers and articles have been selected to highlight technologies and procedures for controlling scale and NORM-scale deposition.

Tomson, M.B., et al, "NORM Scale Formation, Control, and Relation to Gas Hydrate Control," Proceedings of the 10th International Petroleum Environmental Conference, Houston, TX, November 11-14, 2003

The authors of this paper are associated with the Brine Chemistry Consortium at Rice University in Houston, Texas. The consortium includes several major oil companies, large service companies, the National Science Foundation, and the U.S. EPA's Hazardous Substance research Center. The authors describe their and the consortium's study of scale formation and scale inhibitor chemistry. The authors also investigated the effects of hydrate inhibitors, such as methanol and glycol, on scale inhibitor effectiveness. Their work resulted in the development of a model (ScaleSoftPitzer™) which calculates scale inhibitor needs for common scales and includes the effects of hydrate inhibitors. The authors describe the model and its basis and note that it is developed specifically for oil and gas production application. This paper may provide operators with a better understanding of scale formation and control. The paper does not address commercial availability of ScaleSoftPitzer™.

Note: More information on this research and the consortium is available at the following web site: http://cohesion.rice.edu/engineering/brinechemistry/research.cfm?doc_id=2273.

Oddo, J.E., "The Chemistry and Inhibition of NORM Scale Deposition with Field Examples," {Proceedings of the 5th International Petroleum Environmental Conference, Albuquerque, NM, October 20-23, 1998

The author provides a general overview of the occurrence, prediction, and control of NORM in production operations. He explains how NORM is deposited in scale, the concept of the saturation index, and scale prediction using computer models. The author refers to two free scale prediction computer models, including ScaleSoftPitzer™ described in the preceding paper. However, he emphasizes, "It may be best to rely on the advice of an expert unless the user is very familiar with chemical equilibrium models and the complex nature of oil field systems." The author discusses techniques for preventing NORM scale accumulation, such as chemical injection in the well and formation squeezes. His discussion includes evaluation of inhibitor effectiveness (e.g., how to select the correct chemical) and field examples of scale prediction and control.

Zhang, H.R., et al, "Modelling Scale Inhibitor Squeeze Treatments in Horizontal Wells: Model Development and Application," SPE 37140 presented at the 2nd SPE International Conference and Exhibition on Horizontal Well Technology, Calgary, Alberta, November 18-20, 1996

The authors describe a numerical modeling approach for the analysis and design of the field scale inhibitor squeeze strategy for horizontal wells in different types of formations. The model is a two-phase, multi-chemical component near-wellbore simulator. Designing a squeeze for a horizontal well is more complicated than for a vertical well because of the length of the

completion and variability of water influx (and, sometimes water composition) along the wellbore.

Hardy, Greg H. and Khatib, Z.I., "Treatment and Disposal Options for NORM Oil Field Waste," SPE 36586 presented at the SPE Annual Technical Conference and Exhibition, Denver, Colorado, October 6-9, 1996

The authors describe various approaches, in the offshore setting, to minimizing NORM scale deposition and treatment/disposal of oil and gas NORM waste. The authors discuss a technique to predict scale deposition. In this situation, scale deposition was caused by the addition of sulfate ions in injected seawater. In particular, they provide the results of scale inhibitor squeezes to control NORM accumulation. NORM scale deposition was shown to be successfully inhibited, and scale inhibitor was detected in the produced water up to 9 months following a squeeze. The operator used the phosphonic acid inhibitor and Self-Neutralizing Acid Process squeeze processes.

Jordan, M.M., et al, "The Correct Selection and Application Methods for Adsorption and Precipitation Scale Inhibitors for Squeeze Treatments in North Sea Oilfields," SPE 31125 presented at the SPE Formation Damage Control Symposium, Lafayette, LA, February 14-15, 1996

This paper presents a general methodology for the screening of chemical scale inhibitors for both downhole and surface applications. Applying this systematic approach to select inhibitors results in an improved field application strategy with longer squeeze lifetimes, while minimizing formation damage. Although, the paper addresses the application of the method to the North Sea, it is useful in any producing area. The authors note that the method has been applied to over 20 fields.

Kokal, S.L., et al, "Cost Effective Design of Scale Inhibitor Squeeze Treatments Using a Mathematical Model," SPE 29819 presented at the SPE Middle East Oil Show, Bahrain, March 11-14, 1995

The authors present an analysis and design study of scale inhibitor squeeze treatments. A mathematical model was used to simulate inhibitor squeeze return data. The authors describe field applications which validate the model. (Note: This paper was also published in *SPE Production & Facilities* (May 1996), pages 77-82.)

Shuler, P.J., et al, "Diagnosis and Prevention of NORM at Eugene Island 341-A," SPE 29711 presented at the SPE/EPA Exploration & Production Environmental Conference, Houston, Texas March 27-29, 1995

This paper describes Chevron's methodology and actions to identify and control NORM scale precipitation in surface equipment on an offshore production platform. A study was performed to determine the root cause of the scale precipitation and to identify the best, and most cost-effective options for preventing the scale formation. In this instance, mixing of produced waters with different chemistries (one with high barium and others with high sulfates) caused scale precipitation starting in the production headers. Chevron determined that continuous scale inhibitor injection at a wellhead was most effective. Of course, designing production facilities to avoid mixing of incompatible waters (not feasible on Eugene Island 341-A) will reduce or eliminate scale precipitation. Of particular note, Chevron used their experience at Eugene Island 341-A to create a NORM guidebook, or manual, for use in other areas of operation.

Oddo, J.E., et al, "The Mitigation of NORM Scale in the Gulf Coast Regions of Texas and Louisiana: A Laboratory and Field Study," SPE 29710 presented at the SPE/EPA Exploration & Production Environmental Conference, Houston, Texas March 27-29, 1995

The authors discuss a Gas Research Institute study which identified effective scale inhibitors and formation squeeze techniques. The authors also discuss the various ways NORM scale may be deposited. The study, which included laboratory and field tests, resulted in scale inhibitor squeezes which extended effectiveness from an average of two to six months to two to three years. In particular, work in this study identified phosphonates as being more effective in the higher TDS waters and higher temperature regimes that can be expected in the Gulf Coast. This paper will be helpful to an operator investigating ways to reduce scale deposition and NORM accumulation.

Fisher, S.F, "Geologic, Geochemical, and Geographic Controls on NORM in Produced Water from Texas Oil, Gas, and Geothermal Reservoirs," SPE 29709 presented at the SPE/EPA Exploration & Production Environmental Conference, Houston, Texas, March 27-29, 1995

This paper does not address control of scale and NORM, but provides a very good discussion of the various factors that influence NORM occurrence in Texas' oil and gas producing basins. The information provided by the author can be helpful in assessing the probability of scale precipitation and NORM occurrence in water produced from a particular basin and formation.

Smith, G.E., et al, "Economic Impact of Potential NORM Regulations," SPE 29708 presented at the SPE/EPA Exploration & Production Environmental Conference, Houston, TX, March 27-29, 1995

This paper provides a brief overview of current (circa March 1995) state NORM regulations, currently available technologies for management and disposal of NORM wastes, and the costs of employing these techniques. The paper includes a brief, but thorough, background discussion of NORM. Waste minimization techniques for NORM are presented; such as in situ adsorption and scale inhibition treatments.

Malandrino, A., et al, "Mechanistic Study and Modelling of Precipitation Scale Inhibitor Squeeze Processes," SPE 29001 presented at the SPE International Symposium on Oilfield Chemistry, San Antonio, TX, February 14-17, 1995

Graham, G.M., et al, "Development and Application of Accurate Detection and Assay Techniques for Oilfield Scale Inhibitors in Produced Water Samples," SPE 28997 presented at the SPE International Symposium on Oilfield Chemistry, San Antonio, Texas, February 14-17, 1995

The deposition of scale in downhole and surface equipment results in the generation of oil and gas waste (e.g., NORM, well workover wastes). Scale inhibitor formation squeezes have been shown to effectively control scale deposition. However, timing subsequent scale inhibitor squeezes is important. By the time scaling ions are detected, no lead time is allowed for effective scale inhibition. Recognizing this, the authors present laboratory techniques for accurately measuring inhibitor concentrations in produced brines. The presented analytical procedures address phosphonates, polyacrylates, and phosphinopolycarboxylates. Importantly, the authors claim that a working oilfield chemistry laboratory should be able to accurately assay scale inhibitors in produced water. The paper includes appendices which provide analyses procedures.

Sorbie, K.S., et al, "Application of a Scale Inhibitor Squeeze Model To Improve Field Squeeze Treatment Design," SPE 28885 presented at the European Petroleum Conference, London, U.K., October 25-27, 1994

Annotation to be added.

Sorbie, K.S., et al, "The Effect of pH on the Adsorption and Transport of Phosphonate Scale Inhibitor Through Porous Media," SPE 25165 presented at the SPE International Symposium on Oilfield Chemistry, New Orleans, LA, March 2-5, 1993

Annotation to be added.

Paul, J.M., and Fieler, E.R., "A New Solvent for Oilfield Scales," SPE 24847 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, D.C., October 4-7, 1992

The authors describe the development and testing of an effective solvent for scales (e.g., BaSO4). According to the authors, the solvent was developed by Mobil Research and Development. The paper provides a description of the solvent and its components, but does not offer additional detail, such as any hazardous characteristics it may exhibit. However, in field tests the exempt solvent returned from wellbore was disposed of in disposal wells.

Note: The waste minimization advantage associated with use of this solvent is the dissolution and removal of scale from downhole and surface equipment (which includes NORM removal). Therefore, mechanical scale or NORM scale removal is not required. In instances of severe scale deposition, such waste minimization would likely outweigh the disposal of the spent scale solvent in a disposal well. Additionally, the solvent may be beneficial to the injection well.

Gray, P.R., "NORM Contamination in the Petroleum Industry," SPE 22880, *Journal of Petroleum Technology* (January 1993)

This paper addresses the contamination of oil and gas facilities with Naturally Occurring Radioactive Materials (NORM). Radium, radon, and radon decay products are discussed as well as the where NORM may be found in oil and gas facilities. This paper provides a good overview of NORM occurrence and may be helpful in identifying opportunities to reduce NORM accumulation.

Sorbie, K.S., et al, "The Modeling and Design of Scale Inhibitor Squeeze Treatments in Complex Formations," SPE 21024 presented at the SPE International Symposium on Oilfield Chemistry, Anaheim, CA, February 20-22, 1991

This paper provides a detailed discussion of the design of a scale inhibitor squeeze treatment. The authors also describe an improved model for squeeze design.

Pardue, J.E., "A New Inhibitor for Scale Squeeze Applications," " SPE 21023 presented at the SPE International Symposium on Oilfield Chemistry, Anaheim, California, February 20-22, 1991

This paper describes a new scale inhibitor that has a squeeze life double that seen with phosphonate inhibitors. The results of studies in Berea Sandstone cores on calcium precipitation squeezes of a common phosphonate and polymer are presented. The squeeze lifetime with these chemicals has been compared to the lifetime of a new phosphorous containing oligomer. This new inhibitor is as effective as phosphonate inhibitors in controlling calcium carbonate and sulfite scales. It is superior to most products in controlling barium sulfate scales. The method of precipitation has also been studied in order to maximize treatment life. The new phosphorous

containing, oligomeric product should have special utility in reservoirs containing low concentrations of calcium.

Improved scale inhibition can help minimize accumulation of NORM (naturally occurring radioactive materials). Most NORM is found in scale accumulations.

Suzuki, F., et al, "Evaluation of an Anti-Scalant Squeeze Treatment From Pump Run Life and Radiotracer Response in Produced Water," SPE 18487 presented at the SPE International Symposium on Oilfield Chemistry, Houston, Texas, February 8-10, 1989

This paper describes scale inhibitor formation squeeze performance and measurement in wells completed in carbonate formations in Canada. The authors describe the use of radioactive tracers in scale inhibitor and tritiated water to show that "during a 6.5 month test period, 67% of the water was recovered as compared to only 16% of the scale inhibitor." The results indicate the effectiveness of scale inhibitor squeezes. Also, the authors note that pump run life was tripled as a result of the formation treatment. The authors also discuss analytical techniques for observing scale inhibitor concentrations in produced water (including the radioactive tracer), but not in the detail provided in SPE 28997.

Sand Control

Dickerson, R.C., et al, "Horizontal Openhole Gravel Packing with Reactive Shale Present – A Nigeria Case History," SPE 84164 presented at the SPE Annual Technical Conference and Exhibition, Denver, CO, October 5-8, 2003

As this paper's title suggests, the described gravel pack technique was designed to overcome problems with water-reactive shale in a horizontal openhole completion. The authors explain the problems associated with previous gravel pack techniques (e.g., pre-drilled liners or stand-alone screens). Their solution, which is described in great detail, was to use a perforated liner concurrently with a 125-micron woven mesh screen. The concentric flow paths in the resulting annuli allow any blockage to be bypassed, assuring a complete gravel pack. The authors also address the completion fluid makeup which reduced shale reactivity (e.g., increasing KCl concentration). The paper describes the results of this gravel pack installation in several wells. In practically all cases, the technique was highly successful. Effective sand control was achieved, along with improved production. Of course, this reduced the quantity of sand produced to the surface, as well as reducing well workover and surface equipment maintenance needs.

Vaziri, H., et al, "Assessment of Several Sand Prediction Models With Particular Reference to HPHT Wells," SPE 78235 presented at the SPE/ISRM Rock Mechanics Conference, Irving, TX, October 20-23, 2002

The authors discuss conventional models and analyses used to predict sand formation failure and sand production. They note the pros and cons and note certain presumptions which under some circumstances may be improper in predicting sand production. The authors present a alternate model which includes not only sand failure, but also adequate seepage forces to liquefy sand and hence mobilize it. The model also can quantify the volume of sand that may be produced. The benefit of improved sand production prediction is that an optimal production strategy can be developed which reduces the volume of produced sand.

Wu, B., and Tan, C.P., "Sand Production Prediction of Gas Field – Methodology and Field Application," SPE 78234 presented at the SPE/ISRM Rock Mechanics Conference, Irving, TX, October 20-23, 2002

This paper presents a model for sand production prediction in gas wells, The model is based on linear poroelasticity and brittle plasticity with a critical equivalent plastic strain as sand production initiation condition. The model includes the effect of residual strength in the plastic zone surrounding the cavity. The authors very briefly discuss the application of the model to sand formations in a gas well in offshore Australia.

Md Noor, M.Z.B., et al, "Enhanced Gravel-Pack Completions Revitalize a Mature Sand-Producing Field," SPE 77919 presented at the 2002 SPE Asia Pacific Oil & Gas Conference and Exhibition, Melbourne, Australia, October 8-10, 2002

This paper offers an excellent example of produced sand reduction. The authors describe a study of a mature field to improve oil production and explain the need for effective sand control to achieve their goals. The study identified as the best option a combination of sand control and stimulation techniques. The authors describe techniques such as: extension packs; high-rate water pack/high-rate water frac; and enhanced gravel pack proppant/gravel pack sand and wire wrap screen. The case histories provided in the paper demonstrate the success of these completion techniques. The authors state that the field workover has successfully increased the productivity and prevented sand production.

Bigno, Y., et al, "Investigation of Pore-Blocking Mechanism in Gravel Packs in the Management and Control of Fines Migration," SPE 27342 presented at the SPE International Symposium on Formation Damage Control, Lafayette, Louisiana, February 7-10, 1994

The authors present a very technical discussion of pore blocking in gravel packs. A qualified reservoir engineer can use the results of the authors' study to improve gravel pack performance, thus improve control of sand production (i.e., reduce sand production, which minimizes waste).

In their conclusion, the authors' cite their development of a new well performance prediction package for gravel packed wells can be used to predict both the initial and lifetime performance and allowable fines production level necessary for optimum performance.

Bale, A., et al, "Propped Fracturing as a Tool for Sand Control and Reservoir Management," SPE 24992 presented at the European Petroleum Conference, Cannes, France, November 16-18, 1992

This paper describes a fracturing application where increasing production rate was not the prime goal, but rather the modification of the flow profile to allow a more uniform vertical production profile and thereby maximize sand free rates over the perforated section of the reservoir. In best cases for such applications, this technique allows perforating of weak rock to be skipped, reducing risk of sand production and allowing greater wellbore drawdown through perforated intervals in stratigraphically deep and competent reservoir rock. This would allow better long term productivity, improving total recovery and project economics. Details of the formation problem being addressed are discussed in this paper, along with general ideas and theory behind the approach used. Finally, predicted frac behavior and post frac well performance is compared to a field case.

Gunningham, M.C. et al, "Through-Tubing Remedial Treatments Using a Novel Epoxy Resin System," SPE 24986 presented at the European Petroleum Conference, Cannes, France, November 16-18, 1992

A new formulation epoxy resin has been developed, with a solvent system that is compatible with high-expansion elastomers. The versatile epoxy resin system can thus be used with through tubing straddle packers to treat intervals selectively. The system can be used for sand consolidation, water shut-off and cement repairs. This paper describes the laboratory testing of the new system, various applications of the novel epoxy resin and a case history of the first field trial. Laboratory testing of the system has shown that for sand consolidation the system gives 80-90% return permeability while resulting in increases in unconfined compressive strength of typically 50-70 bar. The system can also be used for shut-off purposes, reducing permeability to water by 99%. Gas shut-off may be less effective. The new resin system produces consolidated sand packs with low moduli of elasticity, which may allow them to survive pressure fluctuations better than more rigid formations. The compatibility of the system with high-expansion straddle packers has been field proven.

Dees, J.M., "Sand Control in Wells With Gas Generation and Resin," SPE 24841 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, DC, October 4-7, 1992

The author reviews case histories of 22 treatments with a new sand control procedure applied in Oryx Energy Company wells. The procedure uses an acid curable resin positioned in the casing across the perforated interval in an incompetent sand formation. A gas-frac propellant tool is

placed in the resin and fired to generate gas and drive the resin from the casing and into the formation outside the perforations. Resin remaining in the casing is displaced with gas or water to establish permeability to the non-resin phase, and subsequent acid overflush ensures set of an oil-wet coating of hard plastic which acts as an internal sand control screen. In discussing the case histories, the authors explain the successes and failures and make recommendations for treatment methods based on that experience. In some treatments, production rate from the well was stimulated, which the authors attribute to fracturing pressures from the gas generator surge clearing perforations of formation sand during the resin placement. The authors also explain that the acid curable resin treatment is less costly than conventional gravel packs.

This paper is a good reference for an operator requiring a means of sand control other than a conventional gravel pack. As well as improving well performance, sand control reduces sediment (e.g., in BS&W) at the surface, which eventually must be managed as waste.

Schotts, N.J., et al, "Case Histories of Low-Cost Sand Consolidation in Thermal Wells," SPE 24840 presented at the 66th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, DC, October 4-7, 1992

This paper provides case histories in the application of a new sand control technology using a modified furan resin. The reported benefits of this technique are low cost, thermal stability, environmental safety, and inertness to oilfield chemicals. The sand control process involves consolidating formation material during steam stimulation of a well by injecting the treatment chemical mixed with the catalyst into the steam. After the steam-diluted chemical travels downhole, polymerization occurs on the formation sand grains. Consolidation is completed within a few minutes. Additional shut-in time is not required; the well can be returned to production immediately. Following successful lab testing, field tests were conducted in the Kern River field in Bakersfield, California, using both model test wells and active production wells. The tests determined the optimal treatment conditions for the process. As of publication date, over 100 producing wells had been treated. Results indicate the process reduces sand production without reducing gross production.

Hainey, B.W., and Troncoso, J.C., "Frac-Pack: An Innovative Stimulation and Sand Control Technique," SPE 23777 presented at the SPE International Symposium on Formation Damage Control, Lafayette, LA, February 26-27, 1992

A frac-pack technique combines the stimulation advantages of a highly conductive hydraulic fracture with the sand control of a gravel pack to improve productivity in low to moderate permeability, unconsolidated formations. This paper presents the results of two offshore field tests in the Gulf of Mexico which evaluate different fracturing fluids, unconventional proppant sizes and new gravel packing tools. Aspects of reservoir candidate selection, pre- and post-frac pressure testing, and production results are addressed. This paper examines the layout of equipment, fracture treatment design, and on-site fracture optimization through minifrac testing.

Fahel, R.A., and Brienen, J.W., "A Comparison of Deepwater Sand Control Practices in the Gulf of Mexico," SPE 23772 presented at the SPE International Symposium on Formation Damage Control, Lafayette, LA, February 26-27, 1992

This paper presents the specific techniques for wellbore preparation, perforating, stimulation, gravel packing, and completion hardware used by six companies operating deep water platforms in the Gulf of Mexico. The emphasis here is on specific deep water sand control techniques and the associated methodology and results.

Escobar, J.A., and Turner, W.H., " Practical Experience with Sand Control Completions in Vertical and Horizontal Wells, Bolivia," SPE 23642 presented at the Second Latin American Petroleum Engineering Conference of the Society of Petroleum Engineers, Caracas, Venezuela, March 8-11, 1992

The authors compare sand control methods used in the vertical oil and gas wells with relatively new methods used in the first horizontal well drilled in Bolivia. Even though production from the horizontal well has not exceeded that from nearby vertical wells by the expected margin, initial results are encouraging. Production from a zone previously considered low yield has been at an acceptable level and through a larger choke than is normally used in the area. The sand control methods, gravel pack and perforated pre-packed screens, have been effective, increased production, prolonged useful life of the well, and have not created restrictions which reduce production or flow pressure. Positive results in sand control with the perforated pre-packed filter screens in the horizontal well indicate that this method could be extended to vertical wells.

Santarelli, F.J., et al, "Optimizing the Completion Procedure to Minimize Sand Production Risk," SPE 22797 66th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Dallas, TX, October 6-9, 1991

A numerical model was used to analyze the near well bore of a well to predict the affects of cementation quality and perforation orientation, geometry, and density on sand production. The analysis provides the following results: 1) sand production risk is independent of perforation length, 2) provided perforation density is not too large, sand production risk is independent of perforation entrance hole diameter, 3) large perforation densities increase sand production risk, 4) shooting perforations with a large underbalance will increase sand production risk, 5) a perfect cement job reduces sand production risk, and 6) in a poorly cemented well, perforation orientation will affect sand production risk. The optimum perforation angle is dependent on the in-situ stresses of the formation. The analysis indicates that perforation orientation has little effect on sand production risk in wells with a good cement job.

Veeken, C.A.M., et al, "Sand Production Prediction Review: Developing an Integrated Approach," SPE 22792 66th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Dallas, TX, October 6-9, 1991

This paper discusses three sand prediction techniques: field observations, laboratory testing, and theoretical modeling. The authors critically review the three methods and conclude that integration of the three methods is necessary to alleviate limitations in the individual methods.

Morita, N., and Boyd, P.A., "Typical Sand Production Problems: Case Studies and Strategies for Sand Control," SPE 22739 presented at the 66th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Dallas, TX, October 6-9, 1991

This paper presents five typical sand production problems that are found in the field. These typical sand problems are induced by 1) unconsolidated formations, 2) water break-through for weak to intermediate strength formations, 3) reservoir pressure depletion in relatively strong formations, 4) abnormally high lateral tectonic force in relatively strong formations, and 5) sudden change in flow rate or high flow rate. The authors discuss the five problem areas and offer recommendations for minimizing sand production by choosing the proper completion method. These methods may include avoidance of perforating weak intervals, significant reduction in drawdown, and gravel packing.

Toney, J.B., et al, "Completion Planning for Elimination of Sand Production in Thinly-Bedded Aquifer Gas Storage Wells," SPE 19756 presented at the 64th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, San Antonio, TX, October 8-11, 1989

This paper analyzes the effect of perforation spacing and density on sand production in anisotropic reservoirs. In general, the conclusions of the study indicate that sequentially-spaced, high shot-density perforators minimize completion pressure drops which may cause sand production. The field study showed that this method of perforation did not damage casing. The study was conducted in a gas storage reservoir; however, this perforating method may be applicable to gas or oil completions in similar anisotropic reservoirs.

Ghalambor, A., et al, "Predicting Sand Production in U.S. Gulf Coast Gas Wells Producing Free Water," SPE 17147, *Journal of Petroleum Technology* (December 1989) 1336-1343

Sand production can be predicted using a statistical model using field data from gas wells and log-derived properties of reservoir rock. The model predicts the optimum rate of production that will not induce sand production when free water is being produced. Benefits include the prevention of formation damage, equipment damage, and the volume of produced sand to be managed.

Paraffin Control

See also ""plunger Lift" under "Artificial Lift Alternative" in Section 3. Plunger lift installations have been successfully used in certain applications to control paraffin accumulation in wells.

Becker, J.R., "Potential Environmental Impact from Mishandled Waxy Crude Oils," Proceedings of the 10th International Petroleum Environmental Conference, Houston, TX, November 11-14, 2003

The author discusses the problems associated with paraffin deposition in producing wells and pipelines. He then provides a description of various prediction methods and tests and methods for preventing paraffin deposition. The advantages and disadvantages of the various paraffin control methods is discussed. The paper includes several case histories of successful control of paraffin and the benefits. The case histories typically favor the use of solvents and crystal modifiers for control. In particular, successful control of paraffin in producing wells reduced the need for workovers and eliminated treatments such as hot-oiling. Thus, waste generation is minimized.

This paper is available at http://ipec.utulsa.edu/.

Henson, R.D., et al, "Evaluation of Paraffin-Treating Programs in Rod-Pumped Wells," SPE 27669 presented at the 1994 SPE Permian Basin Oil and Gas Recovery Conference, Midland, Texas, March 16-18, 1994

The authors present a "philosophy of managing a paraffin program." Their suggested paraffin program includes paraffin characterization, effective sampling, and thorough monitoring. Using the results of these tasks, an appropriate treatment method can be selected. The authors discuss treatment methods such as hot-oiling, condensate, hot water, scraping, and inhibitor formation squeezes. This paper is very useful in that the authors describe the problems associated with these treatment methods. The paper's thorough discussion of paraffin, its deposition, and conventional removal techniques may provide incentive to consider alternative treatments (e.g., microbial paraffin control).

Brown, F.G., "Microbes: The Practical and Environmental Safe Solution to Production Problems, Enhanced Production and Enhanced Oil Recovery," SPE 23955 presented at the 1992 SPE Permian Basin Oil and Gas Recovery Conference, Midland, Texas, March 18-20, 1992

The author, of National Parakleen Co. Inc., presents the theory and field application of microbial treating of oilwell systems and reservoirs. In this study, facultative anaerobic microbes were used to control paraffin wax deposition, increase production, and enhance oil recovery in paraffin based crude oils produced from solution gas drive reservoirs. This paper describes how migration microbial enhanced oil recovery (MMEOR) is being used to increase reservoir recovery. The microbial process reduces oil viscosity economically and does not require

expensive well conversions. The process can also be applied to single well and multi-well projects. This process reduces or eliminates paraffin wax crystallization and deposition in the well bore and producing formations, effectively reducing viscosity and pour point. This is an excellent waste minimization technique in that it reduces the need for paraffin solvents and dispersants while increasing oil recovery and operating efficiency.

Pelger, J.W., "Wellbore Stimulation Using Microorganisms To Control and Remediate Existing Paraffin Accumulations," SPE 23813 presented at the SPE International Symposium on Formation Damage Control, Lafayette, Louisiana, February 26-27, 1992

The author, of Bio Tech Inc., describes a method to increase production in individual wells with damage due to paraffin formation and accumulation. Using this technique, an individual treatment is designed from a library of facultative anaerobic microorganisms. The organisms are naturally occurring, non-pathogenic, non-toxic, non-carcinogenic, non- combustible, and require no permit from the Environmental Protection Agency for storage, transportation, or disposal. The author discusses a field application where ninety one wells were treated. In four specific case histories for treated wells, the author provides treatment procedures and economics. The treatments resulted in an production increase of 2,664 barrels of oil per month and 16,045 million cubic feet gas per month. And, the field's operating costs were reduced 18.1% by eliminating chemical treatments and hot oil/hot water treatments.

Santamaria, M.M., and George, R.E., "Controlling Paraffin Deposition Related Problems by the Use of Bacteria Treatments," SPE 22851 presented at the 66th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Dallas, TX, October 6-9, 1991

The use of bacteria to control paraffin deposition in producing oil wells is discussed as an alternative to hot oiling. This process could possibly be applied as such in other areas of oil production, such as in gathering and transportation lines as a supplement to pigging. Additional waste reduction due to the use of paraffin treatments would be from the elimination of the potential for oil spills while handling oil for hot oil treatments. Conclusions of the study were that: 1) application of bacteria for paraffin control is limited to wells that produce water, are pumping wells, and have bottom hole temperatures below 210^{o}F; 2) no obvious alterations to oil properties result; 3) no obvious increase in SRB; 4) hot oiling frequency reduced from twice a week or twice a month to once every six months; and 5) a savings of $8,000/month observed in the 5-well field application.

Hydrate Inhibition

Lovell, D., and Pakulski, M., "Hydrate Inhibition in Gas Wells Treated With Two Low Dosage Hydrate Inhibitors," SPE 75668 presented at the SPE Gas Technology Symposium, Calgary, Alberta, Canada, April 30-May 2, 2002

This paper describes a treatment to control gas hydrate formation in gas wells, which offers an alternative to methanol and other solvents ("thermodynamic inhibitors). In particular, methanol may be costly. Also, storing and using methanol creates the potential for hazardous waste generation. The authors provide a substantive discussion of the alternative treatment using antiagglomerant (AA) and kinetic inhibitor (KI). These inhibitors are non-thermodynamic and inhibit hydrate formation by coating and commingling with hydrate nuclei to interfere with its growth and agglomeration. The authors discuss their chemistry and function in inhibiting hydrate formation. Also, the authors note that these inhibitors are much less toxic than methanol and other solvents used for hydrate inhibition. The paper includes case studies of the successful and cost-effective use of AA and KI in gas wells in Canada.

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SECTION 4

NATURAL GAS TREATING AND PROCESSING OPERATIONS

Natural gas treating and processing is in many instances an integral part of the upstream production operation. Because waste streams generated by natural gas treating and processing are relatively unique, relevant references are presented in this section of this bibliography. Also, because these operations are commonly a part of production, some oil and gas wastes generated in natural gas treating and processing operations are also exempted from classification as hazardous wastes. But, note that natural gas treating, such as dehydration, also occurs along natural gas transportation pipelines, where all wastes are nonexempt.

As noted in Section 3, an operator may still obtain benefits from implementing waste minimization techniques. In natural gas treating and processing operations, air emissions have been a subject of reduction efforts (in part driven by new regulations). This section offers references related to air emission reductions, as well as other technologies, such as deliquescents for gas dehydration. This section provides numerous references which may provide useful information to operators interested in minimizing waste generated by their natural gas treating and processing operations.

Note that many of the references in this section may be also applicable to pipeline transportation operations. Conversely, some of the references in Section 5, "Crude Oil and Natural Gas Pipeline Operations" may be useful in natural gas treating and processing operation.

This section provides references to technical papers and articles which address the following:

4.1 A General Overview of Waste Minimization in Natural Gas Treating and Processing Operations

4.2 Air Emissions

4.3 Improving Operating Efficiency to Reduce Waste Generation

Gas Well Production

Separation and Multi-Phase Measuring

Glycol Dehydration Unit

Deliquescing Desiccants for Gas Dehydration

Electric Motors

Waste Heat Recovery

4.4 Mercury

4.5 Product Substitution

4.6 Recycling

Various

CO2 for Use in EOR

4.1 A General Overview of Waste Minimization in Natural Gas Operations

Mesing, G.E., et al, "Waste Minimization in the Natural Gas Industry: Regulations, Methodology, and Assessment of Alternatives," Gas Research Institute, Topical Report GRI-97/0252 (September 1997)

This Gas Research Institute report is a good resource for information on the natural gas industry's waste generation and management. The report profiles NGI waste generation and provides a thorough discussion of priority waste streams and waste minimization options. Useful features of the report are an economic evaluation of waste minimization options and an extensive waste minimization/pollution prevention bibliography. The report includes a diskette containing the GRI WMIN-Econ program, a computer tool for performing economic analyses of waste minimization options. This report is a great reference for operators interested in developing effective waste minimization programs for their NGI operations.

Fillo, J.P., and Evans, J.M., "Natural Gas Industry Waste Production and Management Practices," SPE 29716 presented at the SPE/EPA Exploration & Production Environmental Conference, Houston, Texas, March 27-29, 1995

The authors present the results of a survey conducted for the Gas Research Institute. The survey results were used to develop representative profiles of the sources, types, quantities, and management of wastes generated by the natural gas industry (NGI). This information is essential to the development and focus of research programs and for the use by NGI to assess their individual waste management/minimization programs. Data was gathered directly from over three dozen operating facilities in eleven states nationwide. This data included facility operations information, waste sources and types, waste volumes and on- and off-site management practices, (e.g., waste minimization, storage, treatment, transportation, and disposal practices). The paper describes the basis for the work, and presents profiles developed for the sources and types of wastes, waste volumes, and waste management practices. The paper discusses waste management practices and their preferential use throughout the NGI and illustrates systematic use of waste minimization practices for the management of selected wastes by the NGI.

J.R. Benoit, J.R., and Schuh, M.G., "Waste Minimization Program at Sour Gas Facilities," SPE 26011 presented at the SPE/EPA Exploration and Production Environmental Conference, San Antonio, Texas, March 7-10, 1993

First and foremost, the authors discuss the development and implementation of a successful waste minimization program. They discuss key elements and benefits. Also, they discuss the waste audit and its use, e.g., analyzing "material balance" to identify opportunities. The waste minimization audit established that this facility spent approximately $1,370,000 annually on waste related activities, services, and purchases. In total 22 significant waste streams were identified at the plant with six being identified as priority wastes. They were lo-cat slurry, produced water, lean oil filters, lube oil filters, lube oil, and washwater. The results of having completed the audit revealed not only improved techniques for handling generated wastes, but also cost savings if the best alternative for each of the six priority wastes were implemented. An in-depth review of alternative practices for managing and minimizing these wastes was undertaken resulting in an estimated savings of $295,000 annually and a disposal volume reduction in the order of 25,000 kilograms (55,000 lbs.). The authors state that a capital expenditure of $395,000 was made to achieve the reductions; therefore, payback was in less than a year and a half. Other benefits were an improved general awareness among plant personnel of wastes associated with various operations, a better understanding of liabilities and costs involved with poor or outdated waste handling and disposal practices, and finally a more optimistic attitude toward waste minimization and management.

4.2 AIR EMISSIONS

Also *see* "Deliquescing Desiccants for Gas Dehydration" in this section.

Robinson, D.R., et al, "ICF Consulting's GHG Emissions Management System (GEMS™)," Proceedings of the 10th International Petroleum Environmental Conference, Houston, TX, November 11-14, 2003

The authors describe a trademarked software for the inventory and management of methane emissions in the natural gas industry. The system may be used in various applications (e.g., Microsoft Excel®). The system provides for a detailed inventory of emissions sources (e.g., distinguishes between low- and high-bleed gas actuated valves). It also provides a means to evaluate alternative technologies for each source, including economic analysis. The economic analysis is designed to allow the user to establish a cost-effective plan for reducing methane emissions. The authors provide a good description of the system and its features. This system may be of interest to operators interested in methane emissions reduction.

Goodyear, M.A., et al, "Vapor Recovery of Natural Gas Using Non-Mechanical Technology," SPE 80599 presented at the SPE/EPA/DOE Exploration and Production Environmental Conference, San Antonio, TX, March 10-12, 2003

The authors describe the design and development of a vapor recovery system for crude oil and condensate tanks. The system uses high pressure gas as the motive gas in a venturi (eductor). The venturi draws gases from the tanks. The venturi discharge, at an intermediate pressure, may be directed to a compressor suction, low-pressure separator, fuel gas system, or flare. The authors describe how the system was designed and configured specifically for a South Texas oil and gas production facility. The cost of installation was about $100,000 with payback in less than four months (based on value of recovered gases). The benefit, as the paper title suggests, is that the system uses no moving part; therefore, it is more efficient and easier to operate and maintain. The system provides waste minimization benefits by greatly reducing air emissions, such as volatile organics and methane. Note that in certain cases, a state will have regulatory requirements to control such emissions; therefore, this system may also help with regulatory compliance.

Note: This vapor recovery unit is described in detail in the U.S. EPA's "Environmental Technology Verification Report, Environmental Vapor Recovery Unit (EVRU)" by COMM Engineering, USA, SRI/USEPA-ghg-vr-19 (September 2002). The report is available on the EPA web site at: http://www.epa.gov/etv/pdfs/vrvs/03_vr_comm.pdf.

Ritter, K., et al, "Application of the API Compendium To Examine Potential Emission Reduction Opportunities for Upstream Operations," SPE 80576 presented at the SPE/EPA/DOE Exploration and Production Environmental Conference, San Antonio, TX, March 10-12, 2003

This paper discusses the API's development of compendium of calculation techniques and emission factors that can be useful for developing greenhouse gas (particularly CO_2 and methane) emissions inventories. The paper also presents several emission reduction opportunities which have been successfully implemented by E&P companies.

(Note that several of the reduction opportunities are from the EPA's Natural Gas Star Program. Natural Gas Star Program technical support documents are available on their web site at http://www.epa.gov/gasstar/.)

Harwell, L.J., and Kuchininski, J., "Upgrade Gives New Life to Old Gas Plant," *Oil and Gas Journal* (November 22, 1999) 57-61

This article describes the conversion of a refrigerated lean oil plant to a high-recovery cryogenic gas plant. The authors provide a description of the plant design and operation. As described by the authors, the new design was very effective in minimizing emissions of NO_x, SO_2, CO_2, and volatile organic compounds.

Gearhart, L.E., "New Glycol-Unit Design Achieves VOC, BTEX Reductions," *Oil and Gas Journal* (July 13, 1998) 61-64

This article presents a field gas glycol dehydration unit design which reduces VOC (including BTEX) emissions without the use of a reboiler vent condenser. The author describes the unit's design which allows reduced glycol circulation rates. The unit also uses a VOC stripper on the glycol going to the reboiler. Removed VOCs are directed to the reboiler for use as fuel. The author also describes emission testing, which demonstrates the reduction in VOC emissions.

Schievelbein, V.H., "Reducing Methane Emissions from Glycol Dehydrators," SPE 37929 presented at the 1997 SPE/EPA Exploration and Production Environmental Conference, Dallas, TX, March 3-5, 1997

The author describes Texaco's installation of methane and VOC recovery systems on their glycol dehydration units. The modifications included installation of a natural gas/glycol heat exchanger and a glycol cooled vapor condenser. The author describes in detail the mechanical and operational aspects of the modifications. He also explains the relationship between glycol circulation rate and methane and VOC emissions. The Gas Technology Institutes emission model, GRI GLYCALC is discussed. The project resulted in impressive methane and VOC emission reduction. Texaco achieved a 95% reduction in methane emissions from Louisiana glycol dehydrator vents between 1990 and 1997.

Breninger, T.L., et al, "Pneumatic Control Devices in Production Areas – Significant Methane Emission Sources?," SPE 37928 presented at the 1997 SPE/EPA Exploration and Production Environmental Conference, Dallas, TX, March 3-5, 1997

The authors describe a pilot study to determine the quantity of methane emissions form control devices at small and medium sized tank batteries. Control devices measured included pressure, level, and temperature controllers. The authors describe the study methodology and results. Of particular interest, the study determined that level controllers emitted the most methane and were the best candidates for cost-effective retrofitting with low-bleed controllers. The level controller retrofits had not been made at the time of the paper's presentation; however, the authors estimated a payback period of approximately 2.5 to 3.2 years.

Scalfano, D.B., "Case History Reducing Methane Emissions From High Bleed Pneumatic Controllers Offshore," SPE 37927 presented at the 1997 SPE/EPA Exploration and Production Environmental Conference, Dallas, TX, March 3-5, 1997

This paper discusses the results of the testing of a low-bleed process controller on two platforms in the Gulf of Mexico. The low-bleed controller ("Mizer valve) can reduce bleed rates by 80% compared to conventional high-bleed controllers. This results in a significant reduction in the quantity of methane released to the atmosphere. The author provides a good explanation of the Mizer valve's installation and operations. He also provides a simple economic analysis using the

costs of retrofit and estimates of methane savings. The author notes problems encountered during the test and offers suggestions for reducing such problems in future controller retrofits using the Mizer valve. This technology is one of the first emphasized by the U.S. EPA's Natural Gas Star Program.

Thompson, P.A., et al, "Using GRI-GLYCalc™ and GRI-HAPCalc™ as Process Optimization Tools," SPE 37912 presented at the 1997 SPE/EPA Exploration and Production Environmental Conference, Dallas, TX, March 3-5, 1997

The authors describe the Gas Research Institute's air emissions modeling programs, GRI-GLYCalc and GRI-HAPCalc. (Both models are Windows-based applications.) These models are excellent tools for determining hazardous air pollutant emissions from natural gas industry processes and equipment. The authors note that several states, including Texas, accept the use of the models for air permitting purposes. Using the models, rather than actual sampling and analysis, can result in significant permitting cost savings. Also, the models allow an operator to asses the operational efficiency of a process (e.g., a glycol dehydrator using GRI-GLYCalc). By using the models to predict the results and feasibility of modifications (e.g., addition of a flash tank to a dehydrator), an operator may implement changes which reduce emissions and save money. The authors present examples of the successful use of the models to achieve such results.

Ferry, K.R., et al, "Air Toxic Emissions Characterization of Natural Gas Processing Plants," SPE 37875 presented at the 1997 SPE/EPA Exploration and Production Environmental Conference, Dallas, TX, March 3-5, 1997

This paper reports on a project by the Gas Research Institute (now Gas Technology Institute) to determine the sources of air emissions from combustion sources at gas processing plants, including internal combustion (IC) engines, incinerators, heaters, boilers, and gas turbines. The authors discuss the methodology used to collect data on emissions of hazardous air pollutants (HAPs) which would be subject to the Clean Air Act. Based on the testing up to the conclusion of the project, formaldehyde was found to be the primary HAP emitted from natural gas-fired combustion equipment. Also, the authors state that internal combustion engines appear to be the most likely to trigger regulatory concern. Regarding waste minimization, the results of the project demonstrated that equipment maintenance and tuning are quite effective in reducing HAP emissions and fuel consumption. The paper includes examples of HAP reductions achieved by performing IC engine maintenance and reconfiguring/tuning incinerators (i.e., flares).

See also: Shareef, G.S., et al, "Measurement of Aldehydes in Internal Combustion Engine Exhaust," SPE 37878 presented at the 1997 SPE/EPA Exploration and Production Environmental Conference, Dallas, TX, March 3-5, 1997. This paper presents further GRI project study which measured and compared emissions from various types of IC engines used in the natural gas industry.

Choi, M.S., and Spisak, C.D., "Aromatic Recovery Unit (ARU): A Process Enhancement for Glycol Dehydrators, SPE 25953 presented at the SPE/EPA Exploration & Production Environmental Conference, San Antonio, Texas, March 7-10, 1993

The authors describe Conoco's patented Aromatic Recovery Unit (ARU) for glycol dehydrators. The authors provide a detailed description of the ARU and the results of its use. The ARU directs non-condensable vapors to the reboiler firetube, condensable vapors (BTEX) to stock tank for sale, and water to disposal. The authors state that for a 30 MMSCFD dehydrator the payout was 8 months and annual rate of return was 147%. Importantly, the ARU significantly reduced emissions of volatile aromatic compounds to the atmosphere.

Gamez, J., et al, "Pilot-Unit Testing of the R-BTEX Process," SPE 25951 presented at the SPE/EPA Exploration & Production Environmental Conference, San Antonio, Texas, March 7-10, 1993

The authors discuss glycol dehydration units, their emissions, and regulatory issues regarding air emissions. In particular, the authors describe the R-BTEX process, which is designed to control the emission of volatile organic compounds (VOCs), including benzene, toluene, ethylbenzene, and xylenes. The R-BTEX process was developed by the Gas Research Institute (GRI) and Radian Corporation. The R-BTEX process recovers VOCs as a saleable product. The authors cite advantages of the R-BTEX process to include its basis in established technologies, its application to new and retrofit glycol dehydration systems, and operation at temperatures well below what can be achieved with competing technologies. This process recovers greater than 95% of BTEX as a salable product, and overall control of VOC emissions is greater than 99% with offgas routed to the reboiler or flare. This level of emission control may help with air regulations compliance. The authors state that economic analysis of the process shows a short payout period. (Note: The R-BTEX Process is commercially available. The Waste Minimization Program can provide information.)

Grizzle, P.L., "Hydrocarbon Emission Estimates and Controls for Natural Gas Glycol Dehydration Units," SPE 25950 presented at the SPE/EPA Exploration & Production Environmental Conference, San Antonio, TX, March 7-10, 1993

This paper presents the results of the analyses of VOC emission estimates and VOC emission control technologies. The conclusion of the analyses was that excellent estimates of BTEX and good estimates of total VOCs can be achieved with rich/lean glycol mass balance. Control technologies discussed include process optimization (e.g. adjustment of glycol circulation rate) and condensation/combustion. The study found that the most cost effective method to reduce emissions is the combination of emission condensate and non-condensable gases as fuel to the reboiler. The author states that prototype units have been developed and are presently in operation in Louisiana and Oklahoma (85% to 95% reduction in emissions).

Choi et al, "Control of Aromatic Emissions from Glycol Dehydrators," SPE 24828 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, D.C., October 4-7, 1992

The authors describe an Aromatic Recovery Unit designed and used by Conoco. Conoco has developed and applied for a patent on a novel addition to the standard glycol dehydration unit. The new design eliminates the emission to air of almost all aromatics and other volatile hydrocarbons. Hydrocarbons normally vented with water vapor, are recovered for use as use as the glycol regenerator fuel (or possibly sold as condensate product). The authors provide a detailed description of the system and include very favorable economics.

The Conoco patent (Patent #5,163,981) was reported in "Method for Controlling the Discharge of Pollutants from Gas Dehydrators," by M.S. Choi in *E&P Environment* (April 2, 1993).

Fang, C.S., et al, "Recovery of Heat and Carbon Dioxide From Compressor Station Exhaust Gas," SPE 9914 presented at the 1981 California Regional Meeting, Bakersfield, California, March 25-26, 1981

The authors (of the University of Southwestern Louisiana and Columbia Gulf Transmission Company) discuss the feasibility of recovering CO_2 from compressor engine exhaust. The authors conclude that gas compressor flue gas has sufficient heat content that heat recovery is practical. Steam and electrical power can be generated in this manner which reduces the utility cost of removing carbon dioxide from the flue gas. A survey of various methods of removing CO_2 from flue gas has shown that monoethanolamine (MEA) is the best chemical absorbent at low pressures available for the process. The authors provide a fairly detailed description of a system to compress, dehydrate, and transport CO_2 to a receiving oil reservoir (10 or 100 miles from the available source). A typical compressor station of 10,000 horsepower will produce 160 tons/day CO_2 while a 20,000 horsepower station will produce 220 tons of CO_2/day. The authors also discuss the economics of the system. This paper is somewhat dated (1981); therefore, the economics may not be useful today. However, the authors present a concept worth investigating. Newer technologies likely can improve the design and economics of such a system. The primary environmental advantage of this system would be a significant reduction of CO_2 emissions, while CO_2 is recycled for miscible flooding enhanced oil recovery.

4.3 IMPROVING OPERATIONAL EFFICIENCY TO REDUCE WASTE GENERATION

Gas Well Production

Ogden, P.K., et al, "Utilization of Gas Satellites to Reduce Environmental Impact in the Cavalier Gas Field," SPE 36052 presented at the International Conference on Health, Safety & Environment, New Orleans, LA, June 9-12, 1996

The author describes PanCanadian's construction and operation of a "gas satellite" production system. Rather than conventional gas treatment at individual wells and a gathering system to the

gas plant, the gas satellite receives untreated gas (with water and liquids), where it is treated and sent to the gas plant. The author discusses the advantages and disadvantages of the gas satellite system. The primary advantages are centralized treatment and control in the field (SCADA can improve operating efficiency) and reduced land use (minimal "footprint" makes landowner happy). Disadvantages include several wells shut in if satellite goes down, two-phase flow between wells and satellite, and wet gas metering (equity issues when multiple interests). The author states that PanCanadian has implemented procedures to overcome these disadvantages (wet metering was not an issue since only one interest owner). Though such a system may not always be desirable, its feasibility should be considered.

See below "Separation and Multi-Phase Measuring," "A DOE-Joint Industry Separation Technology Project Performed by The University of Tulsa Aids Petroleum Industry," by the U.S. DOE National Energy Technology Laboratory.

Separation and Multi-Phase Measuring

National Energy Technology Laboratory, "A DOE-Joint Industry Separation Technology Project Performed by The University of Tulsa Aids Petroleum Industry, *Inside Tech Transfer*, U.S. Department of Energy, (Spring 2002) 1-4

This article describes the development and availability of "a simple, compact, low weight, low cost separator that requires little maintenance and is easy to install and operate." The Gas-Liquid Cylindrical Cyclone (GLCC) is presently available as a two-phase separator and a three-phase version is being developed. The article describe the use of the GSCC by several operators and details the benefits, which include considerable cost savings.

One advantage offered by the GSCC is the ability to "accurately determine the amount of oil-water-gas in multiphase mixtures for transport. Such metering capability would be useful in the operation of a "gas satellite" production system as described in SPE 36052 under "Gas Well Production."

Mehdizadeh, P., Multiphase Measuring Advances," *Oil & Gas Journal* (July 9, 2001) 45-47

The author describes the various uses of multiphase metering for oil, gas, and water. Though not addressed in the article, multiphase metering may be useful in the gas satellite concept presented in SPE 36052 under "Gas Well Production." For a more detailed discussion of multi-phase metering by the author and others, refer to: Ngai, C.C., Brown, M.D., and Mehdizadeh , P., "Performance Test of a High Gas Volume Fraction Multiphase Meter in a Producing Field" SPE 38784 presented at the SPE Annual Technical Conference & Exhibition, San Antonio, 1997.

Glycol Dehydration Unit

Gupta, A., et al, "Reduction of Glycol Loss From Gas Dehydration Unit At Offshore Platform in Bombay Offshore – A Case Study," SPE 36225 presented at the Seventh Abu Dhabi International Petroleum Exhibition and Conference, Abu Dhabi, October 13-16, 1996

The authors provide a thorough discussion of the optimum operation of a glycol dehydration unit (GDU). The subject GDU was experiencing very high glycol loss rates and the attendant problems of incomplete dehydration. The author discuss the mechanisms whereby glycol is lost in the dehydration process (e.g., vaporization, carry over, and mechanical). The paper points out the necessity of laboratory analysis on "rich and lean" glycol streams for foaming characteristics, contaminants, iron content and pH. The authors improved the GDU performance and reduced glycol loss by addressing: the activated carbon filter bed; glycol still and stripper column packing; reboiler temperature; stripping gas pressure; and the inlet gas scrubber. Improvements in these GDU functions significantly reduced glycol consumption and resulted in savings of almost $80,000/year. This paper is a good reference for information on optimizing glycol dehydrator performance and reducing waste generation.

Deliquescing Desiccants for Gas Dehydration

Acor, L., "Design Enhancements to Eliminate Sump Recrystalization in Zero-Emissions Non-Regenerative Desiccant Dryer," presented at the 10th International Petroleum Environmental Conference, Houston, Texas, November 11-14, 2003

The author repeats many of the points made in SPE 82138 (below), but adds a discussion of a design change made to reduce the potential for recrystalization of desiccant salts in the brine sump of the dehydration unit. The design was altered to direct inlet gas through a hydroscopic brine mist prior to contacting the desiccant salt bed. As well as reducing recrystalization in the sup, the redesign also extended the rate of desiccant consumption.

This paper is available at http://ipec.utulsa.edu/.

Acor, L.G., "Benefits of Using Deliquescing Desiccants for Gas Dehydration," SPE 82138 presented at the SPE Production and Operations Symposium, Oklahoma City, Oklahoma, March 23-25, 2003

The author provides a thorough discussion of the use of deliquescing desiccants for drying natural gas under various circumstances. As in SPE 37348 (below), the author notes the waste minimization benefits of deliquescing desiccants, and provides a more thorough overview of its advantages. The author describes improvements in deliquescing desiccant formulation and design, which has greatly reduced the pitfalls associated with its prior use. The author explains that new deliquescing desiccants do not channel, bridge, plug, or "bloom" (i.e., internal hydration). Deliquescing desiccant systems are low maintenance and ideal for unmanned sites.

Operators should assess the applicability of deliquescing desiccants to their dehydration needs. This dehydration technology can be very effective at reducing waste generation. Because the system is closed no gases are emitted, and brine is the only waste stream.

Vavro, M.E., "Minimizing Natural Gas Dehydration Costs With Proper Selection of Dry Bed Desiccants and New Dryer Technology," SPE 37348 presented at the 1996 SPE Eastern Regional Meeting, Columbus, OH, October 23-25, 1996

This paper discusses the use of deliquescents (various blends of alkali earth metal halide salts) as an alternative to conventional gas dehydration systems , such as glycol and regenerative systems. The author notes that deliquescent use has been restricted in the past to low-pressure, low-flow situations. However, he describes improvements (circa 1996) in deliquescents and the design of deliquescent systems (e.g., multi-stage) and argues that the systems are now suitable for broader application. The waste minimization advantages of deliquescent dehydration systems is the elimination of air emissions (the system is closed) and waste fluids (e.g., spent glycol), and reduction of the potential for soil contamination by spilled glycol.

Amine Sweetening Systems

Lopez, M. and Goodwin, B., "Horizontal Pumping System Installed at East Texas Gas Plant," Oil and Gas Journal (July 20, 1998) 68-73

The authors describe equipment modifications made to amine units at a natural gas processing plant in East Texas. The plant's five amine units had been experiencing problems with the positive displacement and vertical can circulating pumps. The problems included frequent failures (e.g., seals and pumps shafts) which incurred high repair costs ($12,000 to $18,000), reduced operating efficiency, and excessive amine losses (500 gallons per month). The plants engineers determined that horizontal multistage centrifugal pumps were the best choice for replacement. The authors provide a thorough description of the design and implementation of the pump modification and the results. In addition to greatly improved operating efficiency and reduced operating costs, the modification significantly reduced amine losses and associated waste generation. The cost savings for the first year of operation were estimated to be more than $60,000. Since the installation of the first HPS unit, UPR has installed eighteen more HPS units in its operations in the United States.

Electric Motors

Elmer, W.G., "Application of Electric-Driven Reciprocating Compressors for Low Pressure Gas Well Compression," SPE 21680 presented at the Production Operations Symposium, Oklahoma City, Oklahoma, April 7-9, 1991

The author (Oryx Energy Co.) describes the rational for choosing electrically driven reciprocating compressors for completed gas wells. Electric motor driven compressors were

chosen instead of gas engine driven integral reciprocating compressors for eight wells in Harper County, Oklahoma. In this case history, the gas wells' bottomhole pressures had declined to the point compression was necessary, but substantial recoverable gas reserves remained in place. The author states that the reasons for choosing the electrically driven compressors were: lower initial investment; decreased maintenance and downtime; and environmental considerations (e.g., anticipated air emission regulations). The author provides a discussion of the relative economics of electric vs. gas engine compression, concluding that in their case history, electric power was preferred. The use of electric motor driven compressors eliminated waste associated with gas engines (e.g., used lubricating oil and filters) that would have otherwise been generated. Also, three gas-actuated valves were replaced by electrically operated valves, eliminating another source of air emission.

Waste Heat Recovery

Mayhew, R.E., "Waste Heat Recovery On Multiple Low-Speed Reciprocating Engines," SPE 11189, *Journal of Petroleum Technology* (September 1984) 1552-1558.

Though this project is somewhat dated, it demonstrates that waste heat can be recovered from multiple low-speed reciprocating engines. The specific design problem was pulsations in the engine exhaust. The authors describe their design process, which proceeded through various problems before reaching an acceptable design. This project was conducted at a natural gas processing plant. The authors do not provide the economics of the project, but note a 500,000 cu ft/D reduction in plant fuel consumption, which was consistent with the design (during a one-week test).

Mayhew, R.E., "Waste Heat Recovery On Multiple Low-Speed Reciprocating Engines," SPE 11109, *Journal of Petroleum Technology* (September 1984) 1552-1558

This paper discusses the design of a waste heat recovery system which accounts for the pulsating exhaust of low-speed reciprocating engines. The low-frequency, high-amplitude pulse exhaust is potentially destructive to a heat recovery system and must be diminished by filtering and improved structural stiffness. Although this paper is a bit dated, it should offer useful information.

Fang, C.S., et al, "Recovery of Heat and Carbon Dioxide From Compressor Station Exhaust Gas," SPE 9914 presented at the 1981 California Regional Meeting, Bakersfield, California, March 25-26, 1981

The authors (of the University of Southwestern Louisiana and Columbia Gulf Transmission Company) discuss the feasibility of recovering CO_2 from compressor engine exhaust. The authors conclude that gas compressor flue gas has sufficient heat content that heat recovery is practical. Steam and electrical power can be generated in this manner which reduces the utility cost of removing carbon dioxide from the flue gas. A survey of various methods of

removing CO_2 from flue gas has shown that monoethanolamine (MEA) is the best chemical absorbent at low pressures available for the process. The authors provide a fairly detailed description of a system to compress, dehydrate, and transport CO_2 to a receiving oil reservoir (10 or 100 miles from the available source). A typical compressor station of 10,000 horsepower will produce 160 tons/day CO_2 while a 20,000 horsepower station will produce 220 tons of CO_2/day. The authors also discuss the economics of the system. This paper is somewhat dated (1981); therefore, the economics may not be useful today. However, the authors present a concept worth investigating. Newer technologies likely can improve the design and economics of such a system. The primary environmental advantage of this system would be a significant reduction of CO_2 emissions, while CO_2 is recycled for miscible flooding enhanced oil recovery.

4.4 MERCURY

Mercury may contaminate waste streams and equipment in natural gas production, treating, and processing operations. In certain producing areas mercury is a naturally occurring in natural gas and condensate. Naturally occurring mercury can accumulate in gas treating and processing equipment and even in downstream pipelines.

Another source of mercury was gauges and meters, but most mercury-based devices have been taken out of service. However, mercury gauges and meters still are found in the field, such as in meter sheds. A common waste stream associated with mercury leakage from meters and gauges is contaminated soil. Of course, any old mercury meters and gauges that remain in the field should be found and sent for mercury recycling.

The following paper offers information on technologies and procedures to reduce waste generation associated with both naturally-occurring mercury and instrument mercury.

Spiric, Z., et al, "Investigation of Mercury Content in Podravina Gas Fields and Environment," Proceedings of the 6th International Petroleum Environmental Conference, Houston, TX, November 16-18, 1999

The authors describe the natural occurrence of elemental mercury in produced natural gas and the development of an effective mercury removal system in a gas processing plant. Two sulfur-impregnated activated carbon beds were shown to be effective in removing mercury from the gas stream. The first bed is placed prior to dehydration and sweetening, and the second, polish bed is placed just prior to the cryogenic plant. The system is designed to achieve less than 0.01 $\mu g/m^3$ mercury in gas entering the cryogenic plant. Environmental monitoring, described by the authors, showed the system effectively minimized mercury emissions to the atmosphere. The authors also describe sampling and analytical equipment. This paper will be of interest to natural gas plant operators concerned with mercury in inlet gas.

Wilhelm, S.M., and McArthur, A., "Removal and Treatment of Mercury Contamination at Gas Processing Plants," SPE 29721 presented at the SPE/EPA Exploration & Production Environmental Conference, Houston, TX March 27-29, 1995

This paper discusses the source and occurrence of elemental mercury and "organic" mercury compounds in gas plant facilities. The paper presents a brief discussion of techniques for preventing the accumulation of mercury in plant equipment and sludges in processing vessels. The authors state that prevention of mercury contamination in gas plant equipment is best accomplished by removing mercury from the gas stream prior to the plant inlet. They describe a removal method called chemisorption. Methods for analyzing gas and condensate streams for mercury content are also presented. In addition to waste minimization techniques, the paper presents treatment techniques for removal and recovery of mercury from contaminated equipment.

4.5 PRODUCT SUBSTITUTION

Lovell, D., and Pakulski, M., "Hydrate Inhibition in Gas Wells Treated With Two Low Dosage Hydrate Inhibitors," SPE 75668 presented at the SPE Gas Technology Symposium, Calgary, Alberta, Canada, April 30-May 2, 2002

This paper describes a treatment to control gas hydrate formation in gas wells, which offers an alternative to methanol and other solvents ("thermodynamic inhibitors). In particular, methanol may be costly. Also, storing and using methanol creates the potential for hazardous waste generation. The authors provide a substantive discussion of the alternative treatment using antiagglomerant (AA) and kinetic inhibitor (KI). These inhibitors are non-thermodynamic and inhibit hydrate formation by coating and commingling with hydrate nuclei to interfere with its growth and agglomeration. The authors discuss their chemistry and function in inhibiting hydrate formation. Also, the authors note that these inhibitors are much less toxic than methanol and other solvents used for hydrate inhibition. The paper includes case studies of the successful and cost-effective use of AA and KI in gas wells in Canada. The AA and KI inhibitors may prove effective in some natural gas processing and pipeline operations.

Dalrymple D., "CrystaSulf^{SM} Process Showing Success at Pilot Plant," *GasTIPS*," Vol. 5 No. 2, Gas Technology Institute (1999) 41-42

This article describes a sulfur recovery process developed by the Gas Research Institute and Radian International. The process, known as CrystaSulf^{SM}, converts gaseous hydrogen sulfide (H_2S) into elemental sulfur using nonaqueous chemistry and solvents. This process can be used to directly treat high pressure sour natural gas and to desulfurize Claus tail gas. GRI and Radian says that the CrystaSulf^{SM} process offers the gas industry significant benefits, including cost savings up to 40%.

Traditional aqueous-based processes often experience problems with foaming, plugging and pump problems in the systems. GRI and Radian designed and constructed a large pilot

CrystaSulf[SM] process at a West Texas gas processing plant. During startup typical pilot plant difficulties were experienced early on and some additional development was required. GRI and Radian addressed those problems and the plant is now meeting the performance goals (which include 98% pure sulfur).

The pilot plant successfully demonstrated that problems with foaming and plugging, and the associated wastes, can be avoided by the CrystaSulf[SM] process. Additionally, the CrystaSulf[SM] technology operates with chemicals that are a fraction of the cost of traditional processes. At the pilot plant the operators found they were able to save over 60% on chemicals used with the CrystaSulf[SM] system compared with the cost of chemicals for the traditional aqueous system. Controlling additives has not been an issue with this technology as there is no need for additives.

Note: CrystaSulf is now commercially available. The Waste Minimization Program can provide information.

4.6 RECYCLING

Various

Hahn, W.J., et al, "Reuse of Spent Natural Gas Liquid Sweetening Solutions," SPE 29733 presented at the SPE/EPA Exploration & Production Environmental Conference, Houston, TX, March 27-29, 1995

This paper discusses a project to reuse spent caustic from a natural gas liquid (NGL) sweetening process as reagent in SOx scrubbers serving steam generators burning H_2S. Each aspect of the project is described in detail. The scrubber performance using spent NGL sweetening caustic was thoroughly evaluated. The data from the project indicated that partially spent caustic solutions can be as effective as virgin reagents for removing SOx and sulfates in an exhaust gas scrubber, with no deleterious effects on emissions control or operating costs. This project is an excellent example of recycling.

CO_2 for Use in EOR

Rawn-Schatzinger, V., "CO_2 Recovery From Flue Gas For Use in EOR," *Eye on Environment*, Vol. 4 No. 1, U.S. Department of Energy National Petroleum Technology Office (January 1999) 6-7

This article describes a system designed by Mitsubishi Heavy Industries of Japan which will recover 99.9% pure CO_2 from flue gas. CO_2 recovery from boiler flue gas has been used in the carbonated beverage industry for years, but the production of CO_2 on a large scale was not economically feasible and did not meet the needs for nationwide clean air standards. Mitsubishi started development of an improved CO_2 recovery system in 1990 and a pilot plant was built in 1991.

The CO_2 generated by the flue gas recovery method has potential in the United States for use in enhanced oil recovery (EOR) projects using CO_2. Costs of using CO_2 could be significantly reduced by recovering CO_2 at power plants (e.g., a 50 megawatt local generation plant) close to a the CO_2 EOR project. Not only is the cost of CO_2 generation less expensive, but the cost of transportation is dramatically reduced, particularly in places where no existing pipelines have been established. A primary advantage cited by the article is the cost to generate CO_2 from flue gas. In 1998, flue gas CO_2 cost $0.76/MSCF, whereas gas turbine generation of CO_2 cost $1.20/MSCF.

Fang, C.S., et al, "Recovery of Heat and Carbon Dioxide From Compressor Station Exhaust Gas," SPE 9914 presented at the 1981 California Regional Meeting, Bakersfield, California, March 25-26, 1981

The authors (of the University of Southwestern Louisiana and Columbia Gulf Transmission Company) discuss the feasibility of recovering CO_2 from compressor engine exhaust. The authors conclude that gas compressor flue gas has sufficient heat content that heat recovery is practical. Steam and electrical power can be generated in this manner which reduces the utility cost of removing carbon dioxide from the flue gas. A survey of various methods of removing CO_2 from flue gas has shown that monoethanolamine (MEA) is the best chemical absorbent at low pressures available for the process. The authors provide a fairly detailed description of a system to compress, dehydrate, and transport CO_2 to a receiving oil reservoir (10 or 100 miles from the available source). A typical compressor station of 10,000 horsepower will produce 160 tons/day CO_2 while a 20,000 horsepower station will produce 220 tons of CO_2/day. The authors also discuss the economics of the system. This paper is somewhat dated (1981); therefore, the economics may not be useful today. However, the authors present a concept worth investigating. Newer technologies likely can improve the design and economics of such a system. The primary environmental advantage of this system would be a significant reduction of CO_2 emissions, while CO_2 is recycled for miscible flooding enhanced oil recovery.

SECTION 5

CRUDE OIL AND NATURAL GAS PIPELINE OPERATIONS

Crude oil and natural gas pipeline operations generate several unique waste streams. Examples include pigging wastes, hydrostatic test water, pipe coating materials, and methane emissions. This section provides references which may offer techniques for reducing the quantity of these and other pipeline wastes.

Also, some of the references in this section may also be useful in natural gas treating and processing operations.

This section provides references to technical papers and articles which address the following:

5.1 General Pipeline Subjects

5.2 Air Emissions

General

Engine Performance and Efficiency

Alternative Compressor Drivers

5.3 Leak Detection

All Pipelines

Natural Gas Pipelines

Crude Oil Pipelines

Equipment At Pipeline Facilities

5.4 Pipeline Coatings

Application

Removal

5.5 Pipeline Integrity Maintenance and Assessment

5.6 Product Substitution

5.1 GENERAL PIPELINE SUBJECTS

Mabry, S. et al, "Coiled Tubing Deployment of 3.5" Tubing To Be Used As Offshore Gas Pipeline," SPE 29635 presented at the Western Regional Meeting, Bakersfield, CA, March 8-10, 1995

This paper describes Shell Western's use of coiled tubing as a natural gas pipeline from offshore wells to onshore facilities. The project was initiated because replacement of the existing, de-rated 8-inch pipeline (which was corroded) required a four-year permitting process. Shell Western determined that 3.5-inch coiled tubing could be installed within the 8-inch pipeline with minimal permitting requirements. The authors provide a detailed description of the project from planning to completion. This project saved time and cost, as well as eliminating the waste generation associated with conventional pipeline construction. Operators may consider this technique in other situations where pipeline replacement is necessary.

Meshkati, N, "An Integrative Micro- and Macroergonomic Framework for the Reduction of Human Error Potential: A Case Study of an Oil and Gas Pipeline System's Control Room," SPE 27298 presented at the Second International Conference on Health, Safety & Environment in Oil & Gas Exploration & production, Jakarta, Indonesia, January 25-27, 1994

The author provides a detailed discussion of the relationship of microergonomics and macroergonomics to the occurrence of pipeline incidents and accidents attributed to human error. He cites a study of control room operations of a U.S.-based oil and gas pipeline company, which found that operator error was the cause of about 31% of 500 incidents involving pipeline failure and subsequent release. The paper includes a fairly lengthy discussion of the science of ergonomics, which may be of interest. More immediately useful is the list of conclusions and recommendations provided by the author.

5.2 AIR EMISSIONS

Also *see* "Air Emissions" in Section 4 for references which may be useful for natural gas pipeline operations.

General

Ritter, K., et al, "Application of the API Compendium To Examine Potential Emission Reduction Opportunities for Upstream Operations," SPE 80576 presented at the SPE/EPA/DOE Exploration and Production Environmental Conference, San Antonio, TX, March 10-12, 2003

This paper discusses the API's development of compendium of calculation techniques and emission factors that can be useful for developing greenhouse gas (particularly CO_2 and

methane) emissions inventories. The paper also presents several emission reduction opportunities which have been successfully implemented by E&P companies.

(Note that several of the reduction opportunities are from the EPA's Natural Gas Star Program. Natural Gas Star Program technical support documents are available on their web site at http://www.epa.gov/gasstar/.)

Engine Performance and Efficiency

Wachowiak, R.D., "ANR Demonstrates Benefits of Continuous Ignition Monitoring," *Pipeline and Gas Industry*, Vol. 82 No.4 (April 1999);

Wachowiak, R.D., "Engine Ignition Monitoring System Sharpens Diagnostics," *Pipeline and Gas Industry*, Vol. 82 No.5 (May 1999);

Wachowiak, R.D., "Ignition Monitor Can Signal Pre-Combustion Chamber Problems," *Pipeline and Gas Industry*, Vol. 82 No.6 (June 1999); and

Wachowiak, R.D., "Ignition Monitoring Can Help Determine Best Spark Plug Gap," *Pipeline and Gas Industry*, Vol. 82 No.7 (July 1999)

Note: These articles are available at http://www.pipe-line.com/. Select "Archive."

This four part series presents the benefits of continuous ignition monitoring on large compressor engines. The author, of ANR Pipeline Co., discusses the installation of continuous in-line secondary ignition monitoring systems on 58 of its large (2,700 to 12,000 hp) engines. Numeric measurements from secondary wave-form significantly enhance the ability of operators and technicians to detect ignition system degradation and view some combustion-environment conditions. By analyzing secondary ignition parameters operators can quickly identify many problems in specific circuits which previously were difficult and time consuming to detect.

The author describes a series of experiments which were set up by introducing various ignition malfunctions. For example, a loss of one plug on a Clark TCVC-20 two-cycle engine (12,000hp V-20) decreased fuel efficiency 2% and increased NOx emissions 7% to 9%. The combustion misfires also increased 20% to 30 % in the faulted cylinder. Without the in-line secondary ignition monitoring system, this condition would go undetected by current monitoring methods until peak-pressure analysis was performed.

The author's articles indicate that continuous ignition monitoring can be effective in reducing air emissions, while improving engine performance and economy.

Alternative Compressor Drivers

Peer, D.J., "Application of Motor-Driven Pipeline Compressors," *Gas Industries Magazine* (February 1997)

This article discusses the merits of replacing some gas turbine engines that operate centrifugal pipeline compressors with electrical motors. Stricter environmental regulations on gas turbine exhaust emissions have increased the difficulty of obtaining a permit to install new gas turbine engines in some highly populated areas with severe air quality problems. One solution has been to install electric motors with variable frequency or variable speed drives. This is especially applicable where the horsepower requirements are 15,000 hp or less. The advantages of the electric motors are they are clean operating (no air emissions), quiet, highly reliable, and have acceptable operating costs. For peak sheaving operations, motors are easier to bring on line and are better suited to frequent starts and stops. Additional savings in power costs can be made if operation can be scheduled for off-peak electrical rates. The paper goes into a technical discussion of design considerations and a discussion of high speed electrical motors versus conventional electric motors with gears. There is no discussion of economic benefits if any.

5.3 LEAK DETECTION

All Pipelines

Quaife, L.R., et al, "A New Pipeline Leak-Location Technique Utilizing a Novel (Patented) Test Fluid and Trained Domestic Dogs," *Source and date of paper unknown*.

The authors, of Esso Resources Canada Ltd., discuss the use of a patented scent additive and trained Labrador Retriever dogs to detect pipe line leaks. The authors state that the dogs can accurately locate pin-hole leaks in pipelines carrying either gas or liquid phase products. The system is dependent on a new patented leak detection fluid. A key component of the test fluid is an azeotrope which is released when a leak occurs and which, by virtue of its high vapor pressure, migrates directly to the soil surface where it is detected in concentrations as low as 1 part per billion by the trained dogs. At the time this paper was published, the system had been employed on 60 projects with a success rate of 100%. The paper summarizes three years of research directed at developing and testing the use of dogs as a leak detection system.

Natural Gas Pipelines

James E. Albrecht, J.E., "Gas Companies Finding Leaks Faster With OMD," *Gas Research Institute Digest* (October 1999)

This article discusses the use of the Optical Methane Detection (OMD) device to locate leaks from natural gas pipelines. The article includes several examples of companies' successful use of the OMD. Development of the OMD began at the Gas Research Institute in 1988, and, over the years, has involved the expertise of Westinghouse Science & Technology Center, Carnegie-

Mellon Research Institute, and a host of utility participants. The product is now under license to Heath Consultants Incorporated, which manufactures and markets the OMD throughout the world.

The OMD is based on the ability of methane gas to absorb specific wavelengths of infrared (IR) light. An IR light source, mounted on one side of the vehicle's front bumper, directs a beam of light at an optical detector mounted at the other end of the bumper. If the vehicle encounters a gas leak plume that intrudes into the IR light beam, the detector responds to the presence of methane and sends a signal to a display panel inside the vehicle. The OMD performs 14,000 measurements per second, which provides an instant response to a gas leak over a wide range of vehicle speeds. The OMD is simple to use, lightweight, and can be quickly mounted on a variety of vehicles.

Most of the benefits to be gained from using the OMD are based on the increase in speed at which the vehicle can be driven and, consequently, the increase in efficiency of surveying. This will be affected by traffic conditions, general survey environment, and by the number and nature of the leaks identified. In addition, benefits vary based on the use of the OMD and miles driven. According to the article, based on assumptions for 8,500 annual survey-miles and a 30 percent improvement in productivity, a company can expect $178,500 in annual savings.

Note: The Gas Technology Institute offers numerous articles and publications on its web site at www.gri.org. An example is "Optical Methane Detector and Related Applications for Improved Gas Leak Surveying" (purchase required).

Erickson, D., and Twaite, D., "Pipeline Integrity Monitoring System for Leak Detection, Control, and Optimization of Wet Gas Pipelines," SPE 36607 presented at the 1996 SPE Annual Technical Conference and Exhibition, Denver, CO, October 6-8, 1996

The authors provide a very detailed description of a combined leak-detection, gas composition tracking system based on a simplified, transient, multiphase, on-line model. The system has several useful features in addition to leak detection: it estimates the liquid content of the pipeline and indicates required pigging to reduce liquid holdup; estimates slug size in front of the pig; controls multiple well flowrates to minimize sand production and keep wells from loading up; and minimizes slugs flooding separators. The system was designed for, and used on, two wet gas pipelines in the North Sea. The system may be useful in other areas. Besides minimizing waste by leak detection, the system also impacts waste generation by allowing more efficient pigging and by reducing sand erosion problems and well loading to minimize the need for maintenance and workovers.

Crude Oil Pipelines

St. Pierre, Jr., B., "Aircraft-Mounted Forward-Looking InfraRed Sensor System for Leak Detection, Spill Response, and Wildlife Imaging on the North Slope of Alaska," SPE 52679 presented at the 1999 SPE/EPA Exploration and Production Environmental Conference, Austin, TX February 28-March 3, 1999

The author describes ARCO Alaska's use of an airborne imaging system to inspect crude oil pipelines for leaks and conditions conducive to leaks. The system, Forward-Looking InfraRed (FLIR), images small differences in temperature; therefore, it can detect warmer spots such as water-soaked pipe insulation and leaking crude oil. The author states that 700 miles of pipeline can be inspected in about three hours flying time. The author explains technology limitations of FLIR, such as solar or thermal loading. FLIR is obviously useful in very cold climates; however, it may also be useful in more southerly climates where periods of cold weather occur during winter.

Equipment At Pipeline Facilities

Cooper, R.E., and Dowell, P.T., "Leak Detection Using A Nitrogen-Helium Gas System," SPE 17680/OSEA 88140 presented at the

The authors describe a more effective and safe leak detection system for oil and gas process equipment. The system uses a nitrogen purge and helium for leak detection. This system is able to detect leaks of a much lower magnitude than conventional hydrostatic testing, and it offers several advantages. Inert nitrogen gas that is used as the pressurizing medium safely purges the process system of oxygen and flammable gases. The helium, in trace amounts, provides a means of detecting leaks as low as 0.03 m^3/yr. A mass spectrometer is used to detect extremely low levels of the helium detector gas. Helium will penetrate leak pathways that hydrostatic test water will not penetrate, which is important for gas processing vessels. An additional advantage is that equipment (e.g., compressors, valve blocks and instrumentation) can actually be operated under simulated working conditions prior to "gas in" conditions. The authors also describe methods of testing and calibration and a brief case history With respect to waste generation, this system eliminates waste hydrostatic test water, and inert nitrogen and helium pose no air pollution threat.

5.4 PIPELINE COATINGS

Application

Hagood, D.S., and Choate, L.C., "Quality Control Assures Successful In-Situ Internal Pipeline Coating Operation: A Case History," SPE 20088 presented at the 60th California Regional Meeting, Ventura, CA, April 4-6, 1990

This paper provides a concise overview of quality control procedures implemented when coating the internal surfaces of sour service flowlines. The project was primarily designed to control corrosion, thus the potential for leaks and pipeline failure. The internal coatings were an alternative to using pipe with sophisticated metallurgy. The authors explain each quality control step, noting that quality control is the primary factor determining success or failure of an in situ internal coating operation. This paper is a bit dated, but the steps described by the authors should remain instructive for current operations.

Removal

Meidinger, B.L., "'Buffy' The Pipe Cleaning Machine," Project Test Results, Rocky Mountain Oilfield Testing Center, http://www.RMOTC.com/Library/Test_Reports.html (March 16, 1998) (Note: Select "In-Service Pipe Cleaning - Plan B Pipeline.")

This paper discusses RMOTC's field testing of a portable, electrically powered, wire wheel machine. The machine is designed to remove pipe coating for pipeline inspection or repair. The equipment is designed to provide an alternative to costly reconditioning methods. Traditional coating removal methods involve sand-blasting, hydro-blasting or manual removal of existing coatings. The "Buffy" machine provides an alternative to generating significant quantities of spent sand blast media.

"Buffy" is comprised of motorized cone wire brushes mounted in a rigid steel band that hinges and locks around the pipe. The machine was equipped with a push button "deadman" switch that immediately shuts down the machine if the operator releases it. The equipment is manually rotated and moved along the pipe for coating removal.

The RMOTC concluded that the equipment provided an effective means of removing old coatings from the surface of pipe without detrimentally affecting the pipe. Importantly, the equipment is a portable unit that could easily be transported to remote locations that would not be practical for traditional methods. Also notable is that the manufacturer has developed an explosion proof model and has manufactured an adapter that will collect all removed coatings in a collection bag for disposal, for application in the removal of asbestos containing coatings.

5.5 PIPELINE INTEGRITY MAINTENANCE AND ASSESSMENT

Common wastes generated in pipeline operations as a result of leaks and spills are contaminated surface water, groundwater, and soil. Pipeline operators must be constantly diligent to prevent leaks and spills, and numerous regulatory requirements address the subject. Pipeline integrity assessments are an important tool in preventing leaks and spills. The following papers and articles offer information on assessing and maintaining pipeline integrity.

Vieth, et al, "Alyeska Program Allows Pig Performance Comparison," *Oil and Gas Journal* (February 10, 1997) 52-59

The authors provide a fairly detailed discussion of the use of data from pipeline inspections using smart pigs. The authors describe how Alyeska developed a methodology to predict the corrosion rate of pipelines in specific areas. The inspection database and methodology has application in decision making regarding the identification of higher risk pipeline sections for excavation and candidate locations for alternative remediation such as cathodic protection upgrades. The methods used in this program permit one to optimize the available data and compare them statistically with measurements of actual external corrosion. Results of the analysis can be used to quantify the performance of past and future inspections and quantify the added value of additional excavations and inspections. The waste minimization component of this methodology is the more efficient prevention of pipeline leaks.

Choumar, A.A., "Pipeline Integrity Through Intelligent Pigging Surveys," SPE 36275 presented at the 7th Abu Dhabi International Petroleum Exhibition and Conference, Abu Dhabi, U.A.E., October 13-16, 1996

The author discusses the objectives, tools, and technology of intelligent pigging surveys (IPS) of pipelines. IPS provides a method of gauging the performance and effectiveness of a pipeline while in service and determines its fitness for continued service. The author provides a good discussion of the two types of IPS tools and their variations: magnetic flux leakage (MFL) tools and ultrasonic tools (U/T). Included in the discussion are the main limitations of each tool type. The author describes measures and precautions for a successful IPS, giving stepwise advice on the use, care, and operation of the devices. Also, IPS can help with the development of a cost-benefit analysis of potential repairs against cost of pipeline replacement.

Heraiba, F., "Evaluation of Pipeline Integrity by On-Line Inspection," SPE 25582 presented at the SPE Middle East Oil Technical Conference & Exhibition, Bahrain, April, 3-6, 1993

Although this paper was presented in 1993, it may still offer some insight regarding inspection tools, specifically magnetic flux leakage tools and ultrasonic tools. The author describes his company's experiences using the tools and highlights strengths and weaknesses of each tool. The tools were used to successfully assess the integrity of a crude oil pipeline system in offshore

Abu Dhabi. The author states that the tools proved to be a valuable and cost effective means to detect defective areas in the pipeline.

Marsili, D.L., and Stevick, G.R., "Reducing the Risk of Ductile Failure on the Carriers CO_2 Pipeline," SPE 20646 presented at the 65th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, New Orleans, LA, September 23-26, 1990

The authors describe a project to determine risk of ductile failure on a CO_2 pipeline and the most effective technology for reducing that risk. At the time of the project, the company determined that the risk was great enough to require preventive measures. The solution was the installation of resin-impregnated, glass-fiber crack arrestors (at an average interval of 3.6 miles on the 220 mile long pipeline. The authors state that project used the Clock Spring™ arrestor, which was developed in conjunction with the Gas Research Institute. The arrestors were low cost and simple to install. Other noted attributes of the arrestors, due to its composition, were minimized corrosion problems and no interference with the cathodic protection system. Although this project was done in the late 1980's, it still may be useful today for both CO_2 and natural gas pipelines. Limiting ductile failure can also limit the quantity of gas released to the atmosphere.

Marshall, G.R., "Cleaning the Valhall Offshore Pipeline," *SPE Production Engineering* (August 1990) 275-278

An assessment of pipeline integrity (e.g., using a magnetic flux leakage tool) requires a clean pipeline. This paper provides an excellent discussion of pigging techniques for cleaning a pipeline, particularly one with significant paraffin deposits. The author describes the decisions made and processes used to clean a subsea crude oil pipeline. The procedure described in the paper may be instructive to anyone planning a pipeline cleaning operation. (Note: This paper is based on SPE 17880, first presented at the 1988 Offshore Technology Conference, Houston, TX, May 2-5, 1988)

Edwards, R.C., "Pipeline Corrosion Logging: A New Application of Wireline Surveys," SPE 17743 presented at the SPE Gas Technology Symposium, Dallas, TX, June 13-15, 1988

This paper examines the operational aspects and performance of a system to measure and interpret corrosion in 3.5" to 12 inch diameter flow lines. The author (Schlumberger) describes the system, which consists of a magnetic flux leakage tool and a video camera. The tools can pass through relatively short length, small diameter flowlines that have extreme bends. Such lines cannot be inspected by the typical tools used in larger transmission pipelines. The author notes that an advantage of the wireline survey is that specific lengths of a flowline with corrosion damage can be identified and replaced; rather than unnecessarily replacing an entire flowline. Also, this survey can prevent a future line failure and release. This paper was presented in 1988; therefore, it is likely this technology has been improved.

5.6 PRODUCT SUBSTITUTION

Lovell, D., and Pakulski, M., "Hydrate Inhibition in Gas Wells Treated With Two Low Dosage Hydrate Inhibitors," SPE 75668 presented at the SPE Gas Technology Symposium, Calgary, Alberta, Canada, April 30-May 2, 2002

This paper describes a treatment to control gas hydrate formation in gas wells, which offers an alternative to methanol and other solvents ("thermodynamic inhibitors). In particular, methanol may be costly. Also, storing and using methanol creates the potential for hazardous waste generation. The authors provide a substantive discussion of the alternative treatment using antiagglomerant (AA) and kinetic inhibitor (KI). These inhibitors are non-thermodynamic and inhibit hydrate formation by coating and commingling with hydrate nuclei to interfere with its growth and agglomeration. The authors discuss the chemistry and function of KI in inhibiting hydrate formation and AA in preventing plugging. Also, the authors note that these inhibitors are much less toxic than methanol and other solvents used for hydrate inhibition. The paper includes case studies of the successful and cost-effective use of AA and KI in gas wells in Canada. The AA and KI inhibitors may prove effective in some natural gas processing and pipeline operations.

Earlier published papers offer discussions of KI and AA as alternatives to thermodynamic hydrate inhibitors for flowlines and pipelines. The authors note that KI and AA are cost-effective when feasible for use. Although most applications are for subsea lines, the application of KI and AA may be in any area of operation. The papers also provide a good overview of hydrate formation. See the following papers:

> Notz, P.K, et al, "The Application of Kinetic Inhibitors to Gas Hydrate Problems," SPE 30913, 1996
>
> Corrigan, A. et al, "Trials of Threshold Hydrate Inhibitors in the Ravenspurn to Cleeton Line," SPE 30696, SPE Production & Facilities (November 1996) 250-255
>
> Kelland, M.A., et al, "A New Generation of Gas Hydrate Inhibitors," SPE 30695 presented at the SPE Annual Technical Conference, Dallas, TX, October 22-25, 1995
>
> Kelland, M.A., et al, "Studies on New Gas Hydrate Inhibitors," SPE 30420 presented at the SPE Offshore Europe Conference, Aberdeen, September 5-8, 1995

SECTION 6

WASTE MINIMIZATION FOR ALL OPERATIONS

Introduction

Many technical papers and articles address waste minimization techniques that may be applied in any type of operation. For example, a SPE 26012 describes a procedure which reduces waste lube oil generated by rig drive engines that may also be applied to diesel engines in other operations (e.g., gas processing plants).

This section provides technical papers and articles which address the following:

6.1 AIR EMISSIONS REDUCTION

Ritter, K., et al, "Application of the API Compendium To Examine Potential Emission Reduction Opportunities for Upstream Operations," SPE 80576 presented at the SPE/EPA/DOE Exploration and Production Environmental Conference, San Antonio, TX, March 10-12, 2003

This paper discusses the API's development of compendium of calculation techniques and emission factors that can be useful for developing greenhouse gas (particularly CO_2 and methane) emissions inventories. The paper also presents several emission reduction opportunities which have been successfully implemented by E&P companies.

(Note that several of the reduction opportunities are from the EPA's Natural Gas Star Program. Natural Gas Star Program technical support documents are available on their web site at http://www.epa.gov/gasstar/.)

Ngai, C.C., et al, "Greenhouse Gas Reduction Strategy: A Team Approach to Resource Management," SPE 35962 presented at the International Conference on Health, Safety & Environment, New Orleans, LA, June 9-12, 1996

The authors describe a team project to assess greenhouse gas (e.g., CO2 and methane) sources in E&P operations and to identify means for reducing emissions. The project team also determined the relative contribution of various operations to greenhouse gas emissions. The project team identified several immediate opportunities for emissions reduction which addressed: AOF tests; dehydrator stripping gas; electric power consumption; transportation; waste heat recovery; fired equipment; and gas-operated glycol pumps. The paper provides a useful table of emission reduction opportunities under the headings: energy conservation; production practice improvement; training and awareness; and other remedial actions. This paper provides a very good example of how emissions control can be successfully and economically implemented.

Müssig, S., "Possibilities for Reduction of Emissions - in Particular the Greenhouse Gases CO_2 and CH_4 - in the Oil and Gas Industry," SPE 25041 presented at the European Petroleum Conference, Cannes, France, November 16-18, 1992

This paper surveys concepts and methods for the reduction of greenhouse gas emissions and other pollutants encountered in the oil and gas industry. Although the paper is a bit dated and addresses oil and gas operations in Germany, the author does offer some useful suggestions for minimizing emissions of CO_2, methane, and various pollutants. Many of the author's suggestions have been refined in recent years (e.g., methane reduction methods identified by the EPA Natural Gas Star member companies).

6.2 CLEANING ALTERNATIVES

Johnston, J.L., and Jackson, L.M., "Field Demonstration of the IC 250™ Cleaning System at the Rocky Mountain Oilfield Testing Center," RMOFTC Project Test Report DOE/RMOTC-020116 (October 5, 1999)

The authors report the results of RMOTC's tests of the effectiveness of a cleaning system which uses small ice crystals. RMOTC used the IC 250™ to remove oil and grease from oilfield equipment including an oil storage tanks, a rod pump, a wellhead, and a road grader. The Ice Clean System is a portable unit that can be built to meet varied electrical codes and marine environmental specifications, utilizing less than 25 gallons per hour of water during the cleaning process. The tests showed that the cleaning system "effectively removed surface contamination mixtures in a timely manner and left no oily residue." The surfaces were contaminated with crude oil, hydraulic fluid, and dirt. The authors also report that "(a) minimal amount of waste moisture was generated, thereby reducing cleanup and disposal costs." Because ice is environmentally safe and contains no toxic chemicals, the system may be an excellent product substitution opportunity. The report does not address the cost benefits of the system.

6.3 CORROSION PROTECTION

Mansour, S. and Binegar, J.S., "Waste Management Practices in the Gulf of Suez – Egypt," SPE 35916 presented at the International Conference on Health, Safety & Environment, New Orleans, LA, June 9-12, 1996.

The authors describe an overall waste management program which primarily deals with offshore drilling and production. Of particular interest is the corrosion protection program developed by the operator (Gulf of Suez Petroleum Company). The program, which adheres to NACE standards, consists of corrosion monitoring, failure analysis, action plan, and post appraisal. The authors note that monitoring is the "cornerstone of the success of the corrosion mitigation program." The authors list the following as components of the monitoring program:

- Weight loss coupons
- Linear polarization probes
- Electrical resistance probes
- Ultrasonic wall thickness measurements
- Chemical analysis
- Hydrogen batch probes
- Cathodic protection surveys
- Coating inspection
- Infrared imaging, radiography, and eddy current.

The authors also describe a few actions taken to mitigate corrosion.

6.4 ELECTRIC POWER EFFICIENCY

PTTC, "Distributed Energy Resources in the Oil Patch," Petroleum Technology Transfer Council publication *Solutions From the Field, Operations and Production*, based on a workshop sponsored by PTTC's Central Gulf and Texas Regions on May 15, 2000, Houston, Texas

This PTTC article provides a good overview of distributed energy resources (DER) and includes several contacts (both supportive organizations and commercial vendors). DER are small-scale onsite power generation and storage devices which can help reduce costs at production sites. Natural gas that is flared may be used to fuel power generation. Besides the benefit of reduced electricity costs, air emissions are reduced. Excess power generated at a site may be sold, further improving the economics of installing DER (you should check with your state's utility commission for applicable regulations regarding this option). This article is available on the PTTC web site at http://www.pttc.org/solutions/oper.htm.

Note: The Texas Public Utility Commission's rules and forms regarding the interconnection of distributed generation are available on the commission's web site at http://www.puc.state.tx.us/rules/rulemake/21220/21220.cfm.

Elmer, W.G., and King, J.D., "New Oilfield Application for Electronic Phase Converters/VSD's," SPE 24833 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, DC, October 4-7, 1992

The authors describe a technology that removes many limitations for the use of single phase power in oilfield applications. Prior to this technology, capacitive and rotary phase converters have been utilized sparingly due to high inrush current and poor motor efficiencies. (As a result, many, if not most, drivers in rural areas have been gas engines.) The technology, a computer controlled solid state power conversion process, eliminates these two problems. The authors discuss actual oilfield applications of the solid state phase converter (SSPC) for fifteen to fifty horsepower motor driven pumping units, compressors, and positive displacement reciprocating pumps. The SSPC provides higher motor efficiency, protects the power distribution system from motor loads and motor malfunctions, provides variable speed drive capability, and is easily used for process control. From a waste minimization standpoint, the advantages are reduced energy requirements, reduced emissions and require minimal lube oil and generate minimal waste.

6.5 ENGINE PERFORMANCE AND EFFICIENCY

See also similar papers and articles under "Crude Oil and Natural Gas Pipeline Operations" in Section 5.

"Contractor Innovation Slashes Pollutants From 2-Stroke Diesel Engines on Drilling Rigs, Buses," ***Drilling Contractor*** **(March/April 1999) 10-11**

This article discusses a rebuild technology for two-stroke diesel engines, including those on well-servicing and drilling rigs. The system includes reengineered camshafts, liners, piston heads, and injectors. According to the article, an engine rebuild using the system ensures that the piston valves open precisely and recirculates exhaust gases, thereby optimizing combustion efficiency. The article cites test results which show that a rebuild using this system significantly reduces emissions (e.g., NOx and particulates), and improves fuel efficiency. As well as reducing emissions, the system is claimed to meet federal and California clean air regulations (as of 1999). The article provides information (including contact information) for the developer and patent holder of the technology. Of note, the technology developer is a drilling company.

Derek Lowe, D., " Electronic Engines Drive Growth at Command Drilling," ***Drilling Contractor*** **(September/October 1998) 59-61**

The author describes Command Drilling Ltd.'s use of "electronic engines" to enhance the company's profitability and reduce environmental impact. Command Drilling equipped new drilling rig diesel drive engines, and repowered units, with an electronic control system called HEUI (Hydraulic Electronic Fuel Injection). The HEUI-controlled engines operated much more efficiently, and gained benefits such as increased horsepower, improved fuel economy (20% to 30%), and reduced exhaust emissions. The HEUI system also monitors and records engine operating parameters and alerts the operator to engine problems, which allows improved, efficient maintenance. Another benefit gained was reduced trucking and set-up costs. The author describes how the more efficient HUEI-controlled engines allowed reconfiguration of drive engine systems such that one engine could replace the previous two-engine set up. This example applies to rigs designed for drilling to 4,000 meters (about 13,000 feet). However, systems such as the HEUI could be applied to any operation using large diesel drive engines.

Ballard, H.N., et al, "An Overview of Exhaust Emissions Regulatory Requirements and Control Technology for Stationary Natural Gas Engines," SPE 24306 presented at the SPE Mid-Continent Gas Symposium, Amarillo, Texas, April 13-14, 1992

This paper offers a practical overview of stationary natural gas engine exhaust emissions control technology and trends in emissions regulatory requirements existing in 1992 (including the Clean Air Act of 1990). Selective and non-selective catalytic reduction and lean burn technologies are compared. The authors also discuss emissions reduction conversion kit developments and a practical approach to continuous monitoring. The reduction of engine emissions is a waste minimization technique which can be used in many areas of the oil and gas industry.

6.6 LABORATORY WASTE REDUCTION

Manning, L. and Grannan, S.E., "Laboratory Waste Management Programs for Research and Field-Support Operations in the Oilfield Servicing Industry," SPE 23376 presented at the First International Conference on Health, Safety, and Environment, The Hague, Netherlands, November 10-14, 1991.

Although the authors present the subject from a service company perspective, their waste management and minimization recommendations can be applied in any laboratory. In particular, a case history demonstrates cost savings realized by reclaiming and reusing certain chemicals. Note that the authors improperly use the term "waste minimization disposal."

6.7 LEAK DETECTION

Hogg, R.S., "Storage Tank Leak Detection Improved With Cable Sensor System," *Oil and Gas Journal* (January 10, 2000) 46-52

The author describes a system for detecting leaks in above ground storage tanks. Since 1995, Kinder Morgan Energy Partners LP has used a cable sensor system for leak detection under tanks and underground valves. The cable sensor system consists of a hydrocarbon sensitive cable connected to a battery-powered electronic flasher module mounted about 3 feet above the tank apron at one end of a 2 inch screened PVC pipe installed beneath the bottom of the tank. The tanks and valves are continuously monitored. The cost of installation of this system was 25-50% less than an alternate technologies (which the author briefly describes). A main compromise that must be accepted in using this system is that it cannot be centrally monitored. Leaks are indicated by above ground flasher units that must be observed by an operator during an inspection. The advantage of this compromise is that power and signal conduits to a central location are not required. This reduces costs and allows more tanks to be monitored for the same investment. The cable sensor system is simple in operation and provides good redundancy because each of the two or more flasher units at each tank is a stand alone leak detection system. Reliable leak detection reduces the potential for pollution and associated cleanup costs.

6.8 PAINTING AND SURFACE PREPARATION

Naval Facilities Engineering Service Center (NFESC) "Carbon Dioxide Blasting Operations,", *Joint Services Pollution Prevention Opportunity Handbook* (revised August 2003) and available at http://p2library.nfesc.navy.mil/

The NFESC offers a fairly detailed overview of the use of solid carbon dioxide pellets (dry ice) as a substitute for sandblast media, chemical cleaning, stripping for surface preparation and cleaning. Technically, CO_2 blasting media is not an abrasive, because it will not abrade the substrate. CO_2 pellet blasting is effective in removal of some paints, sealants, carbon, corrosion deposits, grease, oil and adhesives. The report provides a description of the CO_2 pellet blasting process and highlights its benefits and disadvantages. The primary benefit is a reduction in

waste generation. Rather than spent sandblast media remaining as waste, the CO_2 sublimates in the blasting process.

6.9 PREVENTIVE MAINTENANCE

General

Wisdom, W.L., and Gibson, R.B., "Effective Maintenance Management in Operations," SPE 24075 presented at the Western Regional Meeting, Bakersfield, CA, March 30-April 1, 1992

This paper reports the experience and results of Tidewater Oil Production Company in implementing a Maintenance Management System (MMS) for their field production operations. The system was initiated in order to eliminate unplanned and reactive maintenance work which was both costly and inefficient for the company's operations. This situation was remedied through supervisory training, introduction of a manual, and later, a computer-based maintenance management program. Results of this implementation were a reduction in unscheduled work, increased preventative maintenance, and reduced maintenance personnel.

Storage Tanks

Hein, N.W., and Loudermilk, M.D., "Review of New API-Recommended Practices for Petroleum Production Above Ground Storage Tank Installation, Inspection and Repair," SPE 24552 presented at the 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, DC, October 4-7, 1992

Recent work by API and the industry resulted in new, consensus recommendations for production tanks. These recommended practices have been detailed in a new API document that covers installation, leak detection, inspection requirements, maintenance and repair of the above-ground production storage tanks. Also included in this document are qualification requirements for the three levels of personnel and the different inspections that they can do. This paper reviews the major, new recommended practices and changes to the previous edition of the API Recommended Practice 12R1.

6.10 PRODUCT SUBSTITUTION

No references at this time.

6.11 RECYCLING FOR ALL OPERATIONS

Water

Whitney, P.M., and Greer, C.R., "Evaluation and Comparison of Closed-Loop Wash-Water Systems," SPE 23378 presented at the First International Conference on Health,, Safety and Environment, The Hague, The Netherlands, November 10-14, 1991

This paper presents the results of Schlumberger's field tests of three different types of closed-loop, wash-water treatment systems. The treatment technologies used were mechanical, chemical and biological. Each type of system is described in detail and an evaluation of test results is presented. The conclusion of the tests indicated that closed-loop systems can be successfully used at a reasonable cost. The mechanical system produced the highest quality of recycled water and had the lowest operating cost. The authors also offer specific recommendations for selecting and installing closed-loop, wash-water treatment systems. This test program was conducted at wash bays for wireline oil field service equipment. However, any operation that uses wash bays for vehicles could apply the results of this test program.\

6.12 SCALE INHIBITION AND CONTROL

Labille, S., et al, "An Assessment of Adhesion of Scale and Electrochemical Pre-treatment for the Prevention of Scale Deposition on Metal Surfaces," SPE 74676 presented at the SPE Oilfield Scale Symposium, Aberdeen, United Kingdom, January 30-31, 2002

In a highly technical paper, the authors discuss the laboratory testing of the effectiveness of electrochemical pre-treatment of metal surfaces in inhibiting scale deposition. The authors discuss the need to address heterogeneous nucleation, as well as homogeneous nucleation as mechanisms for the growth of scale. The authors also discuss the effects of corrosion inhibitors on scale inhibitor performance. The information and conclusions provided by this paper may assist persons in improving scale control and reducing the associated waste generation.

6.13 USED OIL REDUCTION

Reller, C.E., "Waste Oil Source Reduction for Diesel engines," SPE 26012 presented at the SPE/EPA Exploration & Production Environmental Conference, San Antonio, Texas, March 7-10, 1993

The author describes in detail a study of the feasibility of determining oil change intervals for diesel engines by using portable field monitors. Incidents of normal and abnormal oil degradation were recorded and correlated between field and laboratory tests. The methodology, equipment used for the tests, and the critical variables are explained. The result of the study indicated that oil change intervals can be extended with analysis and monitoring. The author concludes that, based on a 5,000 hour/year operational period, one facility studied could save over 2,000 gallons of lubricating oil per year. The operating procedure described can

significantly minimize used oil generation. (Note: This study was funded in part by the U.S. EPA under Cooperative Agreement No. CR-817011-01-0 to the Alaska Health Project.)

Fullerton, R.D., "Monitoring Engine Oil," SPE 18663 presented at the 1989 SPE/IADC Drilling Conference, New Orleans, LA, February 28-March 3, 1989

This paper presents the results of a drilling contractor's program to extend the time intervals between oil changes on rig power plant engines. The purpose of the program was to reduce the costs of oil and maintenance; however, the program also resulted in source reduction of waste lubricating oils. The basis of the program was periodic sampling and laboratory analysis of oil samples from each engine. Samples were obtained at each 250-hour interval to establish baseline values for different elements in the oil of each engine. These tests were designed to measure three areas of interest: 1) wear rate of engine components, 2) detection of contaminants, and 3) oil additives. Once baselines were established, oil changes were scheduled based on engine wear or oil contamination as shown by laboratory analyses. The results were an increase in oil change interval from the manufacturer's recommended 500-hour to an average of approximately 1,000-hour for all engines. The author notes that maintenance costs decreased and oil costs of $63.73 per day at the beginning of the program were reduced to $41.15 per day two years later. Although this paper addresses engines on drilling rigs, this technique may be applied in any operation.

York, Marion E., "Extending Engine Life and Reducing Maintenance Through the Use of a Mobil Oil Refiner," SAE 831317, *Proceedings of the International Off-Highway Meeting & Exposition*, Society of Automotive Engineers, Milwaukee, Wisconsin (January 1, 1983)

The by-pass mobil oil refiner is presented in this paper. The mobil oil refiner is a lubricating oil filter/separator that can be installed on engines. The paper describes how the mobil oil refiner operates and a case history of its application on a school bus fleet. The mobil oil refiner improves the properties of lubricating oil in the engine by removing particles of 1 micron and greater size and separating liquids, such as fuel, varnishes and acids. The benefit of the mobil oil refiner is extended engine life and the elimination of regular oil changes (reduction in the quantity of waste lubricating oil). Engine maintenance requirements are also reduced.

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