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WASTE MINIMIZATION IN THE OIL AND GAS INDUSTRIES*

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ABSTRACT

Recent legislative actions place an emphasis on waste minimization as opposed to traditional end-of-pipe waste management. This new philosophy, coupled with increasing waste disposal costs and associated liabilities, sets the stage for investigating waste minimization opportunities in all industries. Many of the wastes generated by oil and gas exploration and production (E&P) and refining activities are regulated as non-hazardous under the Resource Conservation and Recovery Act (RCRA). Potential reclassification of these wastes as hazardous would make minimization of these waste streams even more desirable.

Oil and gas E&P activities generate a wide variety of wastes, although the bulk of the wastes (98%) consists of a single waste stream: produced water. Opportunities to minimize E&P wastes through point source reduction activities are limited by the extractive nature of the industry. Significant waste minimization is possible, however, through recycling. Recycling activities include underground injection of produced water, use of closed-loop drilling systems, reuse of produced water and drilling fluids in other oilfield activities, use of solid debris as construction fill, use of oily wastes as substitutes for road mix and asphalt, landspreading of produced sand for soil enhancement, and roadspreading of suitable aqueous wastes for dust suppression or deicing.

Like the E&P wastes, wastes generated by oil and gas treatment and refining activities cannot be reduced substantially at the point source but can be reduced through recycling. For the most part, extensive recycling and reprocessing of many waste streams already occurs at most petroleum refineries because of the obvious economic incentives. Hydrocarbons are captured from waste streams and cycled back through the refinery to maximize product output. Catalysts, solvents, and other treating agents are regenerated and reused extensively. Opportunities to recycle refinery wastes off-site exist, although they have not been fully developed.

A variety of innovative waste treatment activities have been developed to minimize the toxicity or volume of oily wastes generated by both E&P and refining activities. These treatments include bioremediation, oxidation, biooxidation, incineration, and separation. Application of these treatment processes is still limited; some may prove to be too costly to be practical.

1 INTRODUCTION

Historically, in this country, pollution prevention has focused on end-of-the-pipe waste disposal activities. With respect to solid wastes, environmental regulations developed at both the federal and state levels have focused almost exclusively on ensuring proper waste management through proper waste disposal. Increasingly, regulatory emphasis is being placed on reducing the volume and/or toxicity of wastes *before* disposal. In addition to the potential for more prescriptive regulations, increasing waste disposal costs and associated liabilities are causing industries to focus their attention on the development of new ways to reduce waste volume and toxicity.

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Solid waste streams generated by the oil and gas exploration, production, and refining industries can be reduced through the adoption of a variety of practices. This paper examines the potential for minimizing process-specific wastes generated at oil and gas industry facilities. Waste minimization activities are discussed as they relate to 1) point source volume reduction, 2) recycling of waste or waste components, and 3) toxicity reduction through either product substitution or waste minimization treatment. Wastes that are incidental to activities at these facilities are not discussed in this paper; this includes used oil, paint wastes, batteries, pesticides, oily rags, sanitary wastes, office wastes, etc.

2 OIL AND GAS EXPLORATION AND PRODUCTION

The oil and gas E&P industry generates approximately 21.3 billion barrels of waste each year consisting of 20.9 billion barrels of produced water; 361 million barrels of drilling fluid, drill cuttings, and rigwash; and 11 million barrels of other "associated wastes" (Table 1).[1,2] By virtue of a blanket exemption provided by the 1980 Bevill Amendment and extended by the U.S. Environmental Protection Agency,[3] these wastes are regulated as non-hazardous under Subtitle D of RCRA even though they may exhibit hazardous characteristics defined by RCRA or may be classified as hazardous under other federal regulations. Potential reclassification of these wastes as hazardous would make their minimization even more desirable.

2.1 Waste Stream Constituents

Produced water, drilling fluid, drill cuttings, and rigwash are referred to as high volume wastes. Produced water, which consists of reservoir water produced in conjunction with oil and natural gas, constitutes 98% of the total industry waste stream. Most produced water is a brine (> 3.5% dissolved solids) containing some amount of hydrocarbons, heavy metals (e.g., barium, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc), treating chemicals, solid debris, and possibly radionuclides.[4]

The composition of drilling fluid depends on the specific conditions and requirements of a given drilling operation. Usually it is water-based, although oil-based fluids are used in specific applications. A wide variety of materials are added to the fluid to adjust its weight, viscosity, density, and pH. Other materials are added to control corrosion, bacterial growth, and fluid loss. The main constituents of concern in drilling fluid are arsenic, benzene, sodium, cadmium, chromium VI, boron, and chloride.[1] Drill cuttings consist of subsurface formation material removed from the borehole during drilling; their composition depends on the local geology, but always includes some drilling fluid. Rigwash consists of the fluids that are used to rinse the rig floor, including rainwater; its constituents may include detergents, hydrocarbons, and drilling fluid.

The term "associated wastes" encompasses a variety of low-volume wastes that are derived intrinsically from oil and gas exploration, production, and development activities. This includes wastes generated during workover and completion operations; wastes that collect in the bottom or on the sides of tanks, pits, pipelines, and storage vessels; waste by-products of gas dehydration and sweetening; oily debris; filter media; cooling tower blowdown; and waste hydrocarbons not captured in the production stream. Combined, these wastes make up less than 1% of the total industry waste stream.

2.2 Waste Minimization Opportunities

Significant E&P waste minimization cannot be achieved through point source reductions because, in most cases, the volume of wastes generated by E&P activities depends as much on regional geology, reservoir characteristics, and the age of production as it does on industry processes. This is particularly true for the produced water waste stream which composes approximately 98% of the total industry waste stream. Waste recycling and toxicity reduction activities will provide greater opportunities for E&P waste minimization.

Several E&P waste streams can be recycled in other E&P operations; however, many of the wastes do not lend themselves to reuse within the industry. A number of recycling opportunities external to the E&P industry exist, although they have not been extensively developed. Factors that determine the feasibility of these recycling options include the presence or absence of local markets, transportation costs, treatment costs, and restrictive state regulations.

A number of innovative treatment technologies have been developed to reduce waste hydrocarbon content. Most of these technologies are applicable to wastes generated by E&P and refining processes and are discussed in Section 4.

2.2.1 Produced Water

The volume of produced water generated by a well depends largely on reservoir characteristics and the age of hydrocarbon production, making this waste stream difficult to reduce at the point source. In general, water production is highest from reservoirs whose primary drive mechanism is a water drive, from reservoirs stimulated by a water-flood project, and from old producing fields. The movement of water through a reservoir is a very efficient mechanism for sweeping oil towards a producing well. However, whether the water movement is naturally-occurring, as in a primary water-drive, or induced, as in a water-flood project, the process results in water production. As oil is produced from a reservoir, the underlying water aquifer encroaches on the producing wells and water production increases.

Because the economic burden of handling produced water can determine the profitability of a producing reservoir, incentives to reduce produced water volumes are great. However, efforts that simultaneously jeopardize hydrocarbon production are not appropriate. By following proper reservoir development and production management practices, operators can limit water production rates while increasing oil production rates. In order to keep initial water production rates low and simultaneously preserve high reservoir pressures, producing wells should be completed well above the water-oil transition zone and structurally low wells should be shut-in once water production begins to increase. Wells should be produced at a moderate rate to help prevent coning or fingering of the water aquifer. Horizontal drilling technologies may help reduce water production rates by allowing maximum distances between the well bore perforations and the water-oil transition zone. Care should be taken during drilling, casing, and cementing procedures to prevent poor cement jobs that allow water to enter the borehole. Cement and casing integrity should be evaluated periodically through the use of either electric logs or pressure tests to identify sources of excess water so that repairs can be made in a timely fashion.

Approximately two-thirds of all produced water is reused as injection water in EOR wells. The bulk of this water is used in secondary water-floods. As the development of tertiary recovery projects (e.g., steam flooding, carbon dioxide flooding, polymer flooding, and alkaline flooding) becomes more wide-spread, increasing volumes of produced water may be recycled. Usually, the produced water must be treated before injection to adjust the pH, remove hydrocarbons and solid debris (e.g., produced sand, corrosion, and scale), and precipitate dissolved solids. In some instances, produced water may be reused as the base for drilling fluids or workover fluids. This practice is limited, however, because produced water typically requires extensive treatment or dilution to render it compatible with borehole conditions and drilling fluid constituents. The potential for recycling produced water at other E&P operations depends on the proximity of the other operations and the amount of treatment required.

Produced water also may be recycled by roadspreading, irrigation, or livestock watering, provided its salt and hydrocarbon content are suitable. Roadspreading for dust suppression and deicing is heavily restricted in most states and the use of produced water for irrigation and livestock watering is infrequent. The long range potential for these types of recycling may depend on the development of cost-effective desalinization processes. Greenhouse experiments indicate that water containing up to 1,100 mg/l total dissolved solids (TDS) may improve plant growth if it is applied at controlled rates and intervals, but that water containing more than 1,280 mg/l TDS adversely affects plant growth.[5]

2.2.2 Drilling Fluids

Although the amount of drilling fluid used at a given location is related to somewhat fixed variables: borehole depth and the duration of drilling activities, total volume reductions can be achieved through a recycling process called closed-loop drilling. Ideally, this process reconditions drilling fluid to produce a clean effluent that is recycled back into the mud system as the base fluid. Suspended solids (e.g., drill cuttings) are removed from the drilling fluid by a series of graduated mesh shakers, desanders, desilters, and centrifuges. After the solids are removed, the mud is treated further to remove incorporated gases and to adjust fluid density, pH, viscosity, and weight.[6] When properly designed, a closed-loop system can significantly reduce the volume of liquid initially added to the mud system and subsequently disposed of. The amount of fluid reduction attainable at a particular site through the use of a closed-loop system depends on the amount of solids-control equipment used, the degree to which the drill cuttings break down into fine particles, and the

mud properties (weight, viscosity, and density) desired throughout the drilling operation. Closed-loop drilling can result in lower drilling costs by maintaining mud quality, reducing the volume of base fluid used, reducing the potential for borehole problems, increasing the drilling rate, and reducing the degree of equipment wear.[7] Additionally, reserve pit construction and closure costs are reduced because the volume of waste emplaced in the pit is significantly decreased. Upon completion of the well, water-based muds are disposed of or, less frequently, recycled in some other process. Oil-based muds almost always are retained for use at another location.

Reducing the number of exploratory and development wells drilled in a particular field can reduce the volume of all drilling wastes. Multiple bottom hole locations can limit the number of wells drilled. Similarly, in reservoirs suited to horizontal drilling technology, one horizontal borehole can be drilled in place of several vertical boreholes to achieve the same or greater levels of oil production. It is important to point out that volume reductions through drilling horizontal wells is serendipitous; it is unlikely that a company would elect to drill more costly and difficult horizontal wells just to reduce the volume of drilling wastes.

Drilling fluids can be recycled in several other applications in addition to closed-loop drilling, although the extent to which this occurs is limited. Drilling fluid from one well can be reused at another well either for all or just a portion of the drilling operations. Drilling fluid also can be reused as the packing fluid in workover or completion activities, or in well abandonment procedures. The economic feasibility of these recycling options is determined by the distance between drilling operations (transportation costs range from $6.50-$10.00/barrel), the frequency and continuity of the drilling schedule, and the compatibility of mud compositions between drill sites.[1]

Drilling fluid toxicity reduction is possible through product substitution. Certain drilling fluid additives can be replaced with less toxic substances. Candidates for this type of replacement include biocides, corrosion inhibitors, coagulants, cleaners, dispersants, scale inhibitors, viscofiers, and weighting agents. For example, mineral oil or synthetic polymers can replace diesel additives.[8] Polysaccharide polymers can replace chrome lignosulfonate/sodium chromate for mud thinning, and organic phosphonates/sodium sulfite/ammonium bisulfite can replace chromate/dichromate for corrosion control.[6] Barite containing minimal amounts of cadmium and mercury can be substituted for barite containing greater concentrations of these metals. Additional research is need to quantify the toxicity of each mud additive and, where appropriate, to find substitutes. Research should consider the possibility that some environments, such as wetlands or offshore, are more susceptible to the toxicity of certain additives.

2.2.3 Drill Cuttings

The volume of drill cuttings generated at a specific location largely depends on the depth of the drilled borehole. However, by designing drilling fluid properties so that drill cutting degradation and borehole washout developments are minimized, significant drill cutting volume reductions can be achieved.

Cleaned and sorted drill cuttings may be recycled as road fill, gravel, or cement mix provided the rock composition and metal contents are suitable. Cuttings from one interval of a borehole may be better suited for these uses than cuttings from other intervals due to lithologic differences. The cuttings must be cleaned to remove entrained drilling fluid and fine clay particles, and sorted into sand and gravel fractions. Cleaning processes include draining, detergent washing, thermal treatment, solvent extraction, and incineration. Cuttings generated during drilling with an oil-based mud are suitable for reuse as asphalt or road mix with little or no treatment if the cuttings are non-ignitable and have mixed density values and metal contents consistent with approved road oils and mixes.

2.2.4 Rigwash

The volume of rigwash generated at a specific location depends largely on the duration of drilling operations and the frequency of cleaning activities. Realistically, significant rigwash volume reductions cannot be achieved; however, some reduction may be possible if rig washing is performed only as often as is necessary to maintain safe drilling operations.

2.2.5 Associated Wastes

A wide variety of waste minimization opportunities are available for associated wastes. Reserve pit waste volumes can be reduced by using a closed-loop drilling system, recycling well-site wastewater (e.g., pump lubrication water), constructing trenches to divert surface water drainage away from the pit, and constructing smaller pits to reduce rainwater collection. In situ evaporation of reserve pit fluids using high-pressure spraying equipment also reduces the volume of pit wastes that must be disposed of.[6] Reducing the reserve pit waste streams decreases the pit size needed. This in turn decreases the size of drilling pad needed, reducing site construction costs and impact to the environment.

Storage tank bottoms can be decreased in several ways. Reducing the amount of time the crude is stored in the tank or placing a recirculating pump inside the tank decreases the amount of material that settles to the bottom. The buildup of resins and gums inside a storage tank, resulting from long-term contact between crude oil and atmospheric oxygen, can be lessened by the use of floating-roof tanks or inert gas blanketing which limit the exposure of the stored crude oil to the atmosphere.[9] Oily wastes removed from tanks and other vessels can be recycled as substitutes for road oil, road mix, or asphalt.

Many liquid associated wastes and the effluents derived from their treatment are commingled with produced water for disposal. These wastes may be suitable for recycling along with the produced water. They include packing fluids, used treatment and stimulation fluids, tight emulsions with low hydrocarbon contents, water recovered from emulsion-breaking, liquid recovered from dewatered bottom sludges, inert gas dehydration and sweetening agents, water recovered from gas dehydration, and cooling tower water. Packing fluids also may be recycled from one operation to another provided the continuity of the work schedule and the distance between operations is conducive.

Cooling tower water can be recycled extensively within the cooling system, although treatment is necessary to filter out solid debris and add biocides and corrosion inhibitors. The chlorine biocides and chromate- or zinc-based corrosion inhibitors typically used can be replaced with less toxic products. Substitute biocides include isothiazolin, carbamates, amines, gluteraldehydes, and ultraviolet light; substitute corrosion inhibitors include organic phosphonates and bisulfites.[10,11]

Produced sand recovered from tank bottoms, pit bottoms, production separators, and fluid treaters is suitable for reuse as road fill or construction material if it is treated to remove entrained hydrocarbons. Produced sand also can be used to enhance agricultural soils provided it meets state regulations controlling salt and hydrocarbon content of landspread wastes. When added to clay-rich soils, produced sand can improve drainage and erosion-control.

Almost all hydrocarbons not captured in the production stream are recovered from other waste streams for sale. This recovery renders the waste less toxic and, in some instances, more suitable for recycling. Tight emulsions and hydrocarbon-rich bottom wastes are treated by mechanical, physical, and chemical processes to recover the entrapped hydrocarbons. Paraffin that accumulates inside pipelines is removed by scraping or by the injection of hot oil and is combined with the crude oil for sale to the refinery.

3 OIL AND GAS TREATMENT AND REFINING

Oil and gas treatment and refinery operations vary significantly from plant to plant, depending on the composition of the inlet crude or gas, and the desired product requirements. Waste volume and composition varies widely depending on refinery and treatment activities; however, data describing these variations are limited. Refinery wastes that are listed as hazardous wastes under RCRA Subtitle C have been extensively characterized; however, they represent only a few of the industry waste streams.

3.1 Waste Stream Constituents

3.1.1 Natural Gas Treatment Wastes

Natural gas is treated before sale to remove impurities such as water vapor, free condensed water (condensate), acid gases (H_2S and CO_2), and solid debris. Treatment can occur at field treatment facilities or gas processing plants.

Natural gas may be processed further before sale to recover light hydrocarbon fractions (i.e., ethane, propane, butane, and pentane) that can be liquified and recovered from natural gas. The extraction of natural gas liquids occurs at both gas processing plants and crude oil refineries.

Gas treatment wastes include dehydration and sweetening wastes, produced water, produced sand, pigging wastes, and pipe scale or corrosion. Constituents of concern include hydrocarbons, heavy metals, and possibly radionuclides. When these wastes are generated at field treatment facilities or centralized gas processing plants, they are exempt from RCRA Subtitle C regulations as part of the oil and gas E&P waste stream. When generated at an oil refinery, these wastes are not exempt from Subtitle C regulations if they exhibit hazardous characteristics.

Wastes generated by the extraction of natural gas liquids are limited because the product stream is completely fractionated into natural gas liquids and processed gas all of which are marketable products. The largest waste stream associated with natural gas processing is plant processing and system cooling water. Data describing the volumes of wastes streams generated at gas processing plants are not available.

3.1.2 Oil Refinery Wastes

An industry-wide survey of waste management practices at domestic oil refineries indicates that approximately 16 million (wet) tons of wastes are generated each year.[12] This volume, which does not include plant process or storm sewer wastewater, equals less than 1% of the total crude throughput. Refinery wastes can be divided into five main categories based on their composition: oily sludges and other organic wastes, aqueous wastes, chemical and inorganic wastes, contaminated soils and solids, and spent catalysts (Table 2).[12] Five of the process-related waste streams are listed as hazardous under RCRA Subtitle C; these are dissolved air flotation (DAF) float, API separator sludge, slop oil emulsion solids, leaded tank bottoms, and heat exchanger bundle cleaning sludge. Combined, these waste streams constitute approximately 25% of the total industry wastes. Other wastes may be hazardous if they contain listed substances or exhibit hazardous characteristics.

Oily sludges and other organic wastes comprise 36% of the total industry waste stream. The bulk of these wastes are oily sludges generated by wastewater treatment processes that remove crude oil and solid debris from the water. This includes API separator sludge, slop oil emulsion solids, DAF float, and other separator sludges. Also included in this category are oily sludges that accumulate in the bottom of storage tanks and wastewater treatment ponds, waste oils, spent solvents, desalter sludge, and other organic wastes.

A variety of refinery activities generate aqueous wastes which make up 22% of the total industry waste stream. Most wastewater is treated at on-site wastewater treatment facilities to remove hydrocarbons and solid debris, and to adjust pH. Biomass, which consists of dead bacteria derived from activated sludge treatment of wastewater, is included in this category because it usually contains large amounts of water.

Chemical and inorganic wastes comprise approximately 21% of the total industry waste stream. These wastes are generated through a variety of plant processes including crude fractionation, product treatment, and equipment cleaning. This category includes spent caustic, spent acids, waste amines, and other inorganic wastes (e.g., lime sludge, ion exchange resin, cooling tower sludge, acid or caustic cleaners, and others).

Approximately 8% of the total industry waste stream is comprised of contaminated soils and solids. These wastes include crude- or product-contaminated soils, filters, wax, etc.; waste coke, carbon, and charcoal not recycled to the coke unit; waste sulfur recovered from gas or crude sweetening treatments or the treatment of sulfurous wastes; and heat exchanger bundle cleaning sludge.

Spent catalysts, used in several different crude treatment processes, constitute only 5% of the total industry waste stream. This category includes fluid cracking catalysts (FCC), hydrotreating catalysts, and other spent catalysts (e.g., reformer, shift converter, or metallic catalysts).

3.2 Waste Minimization Opportunities

Some point source waste reductions can be achieved at oil and gas refineries through the installation of newer, more efficient processing equipment and the adoption of better site management practices. However, potentially greater waste minimization gains can be achieved through waste recycling. Efforts to capture hydrocarbons from waste streams and cycle them back through the refinery are integral to most processes. In addition, there are a number of other recycling activities that can be implemented both on-site and off-site to handle other waste stream constituents. These activities, along with opportunities to use less toxic substitute products, need to be more aggressively pursued.

3.2.1 Oily Wastes

Hydrocarbons can be recovered from most of the oily waste streams and recycled through plant processes to increase product output. The recovered hydrocarbons usually are fed into the coke or crude units for reprocessing, although some amount of hydrocarbons also may be burned as fuel in on-site industrial furnaces.

Storage tank bottoms can be decreased by limiting crude residence time in a particular tank, installing recirculating pumps in the tank, and using floating roof tanks or inert gas blankets. Wastewater treatment sludge volumes can be reduced by controlling the amount of oil and solid debris that enter aqueous waste streams and by segregating aqueous waste streams that do not contain hydrocarbons from streams that do.

3.2.2 Aqueous Wastes

Effluent derived from dewatered wastes and water released from the refinery's wastewater treatment facility can be recycled on-site as feedwater for the refining processes, desalter unit, or cooling system. Treatment of the effluent before recycling may be needed to remove solid debris and hydrocarbons, or to neutralize the pH.

Chlorine biocides added to cooling water can be replaced with less toxic substances such as isothiazolin, carbamates, amines, gluteraldehydes, and ultraviolet light. Organic phosphonates and bisulfites may be suitable substitutes for chrome- and zinc-based corrosion inhibitors.

3.2.3 Chemical/Inorganic Wastes

Some of the chemical refinery wastes have properties that make them suitable substitutes for waste treatment agents. For example, acidic wastes may be neutralized by the addition of spent caustics or lime slurries produced by water softening treatments. Some acidic cleaning solutions can be replaced with organic acids and blasting media.

3.2.4 Contaminated Soils and Solids

Some contaminated soils and solids can be sold off-site for other industrial uses. Waste coke, carbon, and charcoal are suitable for sale as industrial fuel and recovered waste sulfur can be converted into elemental sulfur and marketed.

3.2.5 Spent Catalysts

Spent catalysts are reclaimed and regenerated for reuse at the refinery as much as possible. Regeneration, which consists of the removal of coke and tar build-ups, may be an energy-intensive process; however, regeneration and reuse usually is less costly than replacing the catalysts. The recovered coke and tar typically are recycled to the coke unit.

Some catalysts can be recycled off-site. Spent FCC catalysts from one refinery may have additional life at another refinery if different crude compositions are being treated. Otherwise, it can be used as a raw material in cement manufacturing. Hydrotreating catalysts may be useful in processes that reclaim metals from other wastes like coal fly ash.

4 WASTE TREATMENT

A variety of innovative treatment technologies have been developed in the last few years to mitigate the hydrocarbon content of oil-contaminated wastes such as those generated by E&P and refining activities. Wastes that are suitable for these treatments include tank bottoms, pit sludges, separator sludges, contaminated soils, and some wastewater streams.

A number of oxidation processes potentially can eliminate all or most of the hydrocarbons present in oily wastes. Bioremediation can reduce hydrocarbon content in oily sludges by as much as 80%.[13] at an average cost of $150/ton.[14] Biooxidation (artificial wetlands) can reduce parameter concentrations in refinery wastewater by 90 - 100% for considerably less expense than more conventional wastewater treatment systems.[15] Other oxidation treatments that reduce hydrocarbon content include ozonation (exposure to pure ozone atmospheres), electrolysis, and electroosmosis.[16] Oxidation by incineration (e.g., pyrolysis, fluidized-bed incineration, molten salt incineration, and infrared incineration) can remove all hydrocarbons present in a waste.

Other technologies recover hydrocarbon from the wastes for resale. New separation processes using hydrocloncs and membrane filtration techniques have been developed to remove oil from liquid waste streams like produced water.[17] These alternative methods may prove to be preferable to traditional separation processes because they produce effluent of consistent quality and are less sensitive to variable influent oil concentrations. In addition, new cleaning agents have been developed to recover between 60 - 90% of the waste oil from drill cuttings and other contaminated solids.[18]

Most of these new technologies have not been developed for widespread commercial applications; additional research and development may be necessary to ensure these technologies are economic. Processes that can be performed in situ or that recover the hydrocarbons in a marketable state may prove to be most economic; however, with increasing disposal costs and liability concerns, the economic feasibility of all of these technologies will improve.

5 REFERENCES

1. EPA, (1987), *Report to Congress: Management of Wastes from the Exploration, Development, and Production of Crude Oil, Natural Gas, and Geothermal Energy*, EPA 530-SW-88-03, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C.

2. API, (1987), *Oil and Gas Industry Exploration and Production Wastes*, Document No. 471-01-09, American Petroleum Institute, Dallas.

3. EPA, (1988), *Regulatory Determination for Oil and Gas and Geothermal Exploration, Development and Production Wastes*, U.S. Environmental Protection Agency, Federal Register, vol. 53, no. 129, pp. 25446-25459.

4. Stephenson, M.T., (1992), "Components of Produced Water: A Compilation of Industry Studies", *Journal of Petroleum Technology*, vol. 44, no. 5, pp. 548-603.

5. Vickers, D.T., (1990), *Disposal Practices for Waste Waters from Coalbed Methane Extraction in the Black Warrior Basin, Alabama*, Proc. 1st International Symp. on Oil and Gas Exploration and Production Waste Management Practices, U.S. Environmental Protection Agency, New Orleans, pp. 255-266.

6. Lal, M., and N.E. Thurber, (1988), *Drilling Wastes Management and Closed-Loop Systems*, Drilling Wastes, Proc. International Conf. on Drilling Wastes, Calgary, Alberta, Canada, pp. 213-228.

7. Churchwell, R.C., (1981), "Closed-Loop System Controls Mud Solids", *Petroleum Engineer International*, vol. 53, no. 11, pp. 132-140.

8. Fitzpatrick, M., (1989), *Waste Minimization in the Petroleum Industry*, Proc. Conf. on Prevention and Treatment of Groundwater and Soil Contamination in Petroleum Exploration and Production, Calgary, Alberta, Canada, pp. 20.0-20.15.

9. Fromm, C.H. and S. Budaraju, (1988), "Reducing Equipment-Cleaning Wastes", *Chemical Engineering*, vol. 95, no. 10, pp. 117-122.

10. Thurber, N.E., (1990), *Waste Minimization in E&P Operations*, Proc. 1st International Symp. on Oil and Gas Exploration and Production Waste Management Practices, U.S. Environmental Protection Agency, New Orleans, pp. 1039-1052.

11. Hunt, G.E., (1990), "Waste Reduction Techniques: An Overview", *Pollution Prevention Review*, vol. 1, no. 1, pp. 13-26.

12. API, (1991), *The Generation and Management of Wastes and Secondary Materials in the Petroleum Refining Industry: 1987 - 1988*, API Publication 4530, Health and Environmental Affairs Department, American Petroleum Institute, Washington, D.C., 43 pp.

13. Marks, R.E., S.D. Field, and A. Wojtanowicz, (1987), *Oil Reduction in Drilling Wastes by Biological Treatment*, Proc. National Conf. on Drilling Muds, Environmental and Ground Water Institute, University of Oklahoma, Norman, Okla., pp. 78-104.

14. Oppenheimer, C.H., (1991), personal communication from C.H. Oppenheimer, University of Texas, Austin, Tex., to K.P. Smith, Argonne National Laboratory, Argonne, Ill.

15. Litchfield, D.K., (1991), *Constructed Wetlands for Wastewater Treatment at Amoco Oil Refinery in Mandan, North Dakota*, Abstracts from International Symp. on Constructed Wetlands for Water Quality Improvement, Wetlands Laboratory and University of West Florida, Pensacola, Florida, p. 98.

16. Hinchee, R.E., et al., (1989), *Electro Acoustical Soil Decontamination for Enhanced Hydrocarbon Recovery From Soil*, Proc. Conf. on Prevention and Treatment of Groundwater and Soil Contamination in Petroleum Exploration and Production, Calgary, Alberta, Canada, pp. 25.0-25.19.

17. Simms, K., S. Kok, and A. Zaidi, (1990), *Alternative Processes for the Removal of Oil from Oilfield Brines*, Proc. 1st International Symp. on Oil and Gas Exploration and Production Waste Management Practices, U.S. Environmental Protection Agency, New Orleans, pp. 17-30.

18. Shaw, G., and B. Slater, (1990), *BP Superwetter -- An Off-Shore Solution to the Cuttings Cleaning Problem*, Proc. 1st International Symp. on Oil and Gas Exploration and Production Waste Management Practices, U.S. Environmental Protection Agency, New Orleans, pp. 117-128.

WASTE STREAM	VOLUME (10^6 barrels)	PERCENT (% total wastes)
Produced Water	20,900	98.3
Drilling Wastes Drilling fluid Drill cuttings Rigwash	361	1.7
Associated Wastes	11	*
TOTAL:	21,272	100

* less than 0.10 percent

TABLE 1: Wastes Generated by E&P Activities in 1985[1,2]

WASTE STREAM	VOLUME (10^3 wet tons)	PERCENT (% total wastes)
Oily Sludges/Other Organic Wastes	1,809	36
Aqueous Waste	1,077	22
Chemicals/Inorganic Wastes	1,032	21
Contaminated Soils/Solids	402	8
Spent Catalysts	266	5
Other Wastes	412	8
TOTAL:	4,998	100

TABLE 2: Wastes Generated at Crude Refineries in 1988[12]

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